THAMES RIVER FLOOD CONTROL PROJECT

# NORWICH CHANNEL IMPROVEMENT

## SHETUCKET RIVER, CONN.

## ANALYSIS OF DESIGN

### ITEM NW-1

WAR DEPARTMENT CORPS OF ENGINEERS U. S. ARMY
U. S. ENGINEER OFFICE PROVIDENCE, R. I.

OCTOBER 1944

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INDEX

# I. INTRODUCTION

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## A. AUTHORIZATION.

1. Preliminary Authorization. - The Flood Control Act approved 28 June 1938 (Public No. 761, 75th Congress, 3rd Session), states:

> "The Secretary of War is hereby authorized and directed to cause preliminary examinations and surveys for flood control . . . at the following named localities . . .:
>
> Thames River and its tributaries, Connecticut."

a. Survey Report and Review. - The Chief of Engineers authorized a survey report with the stipulation that it be combined with the review of the report and submitted under the provisions of House Document No. 308, 69th Congress, 1st Session in accordance with a recommendation made on 28 December 1938 by the Board of Rivers and Harbors. The review was authorized by the Chief of Engineers pursuant to a Resolution of the Committee on Commerce of the United States Senate, adopted 25 October 1938 and quoted in part as follows:

> "Resolved . . ., that the Board of Engineers for Rivers and Harbors, . . ., be, and is hereby, requested to review the report on the Thames River and tributaries, contained in House Document Numbered 644, Seventy-first Congress, third session, for the purpose of determining flood-protection measures for the Thames River and tributaries, including the Quinebaug River at Southbridge, Massachusetts."

The review was also authorized by the Chief of Engineers, pursuant to a Resolution of the Committee of Commerce of the United States Senate adopted 4 November 1938, quoted in part as follows:

> "Resolved, . . ., that the Board of Engineers for Rivers and Harbors, ..., be and is hereby, requested to review the report on the Thames

River, published as House Document Numbered 644, Seventy-first Congress, third session, with a view to determining what measures or projects should be undertaken at the present time for the control of floods."

2. Definite Authorization. - The flood protection plan for the Thames River Basin, which includes seven reservoirs on tributaries of the Thames River as well as the Norwich Channel Improvement Project, was authorized by the Flood Control Act approved 18 August 1941 (Public No. 228, 77th Congress) which reads in part as follows:

> "Sec. 3. That the following works of improvement for the benefit of navigation and the control of destructive flood waters and other purposes are hereby adopted and authorized in the interest of national security and the stabilization of employment, and shall be prosecuted as speedily as may be consistent with the budgetary requirements, under the direction of the Secretary of War and the supervision of the Chief of Engineers in accordance with the plans in the respective reports hereinafter designated and subject to the conditions set forth therein: . . .
>
> * * * * * * * * *
>
> THAMES RIVER BASIN
>
> The plan for a system of reservoirs and channel improvements in the Thames River Basin, Connecticut, Rhode Island and Massachusetts, in accordance with the recommendation of the Chief of Engineers in House Document Numbered 885, Seventy-sixth Congress, Third Session, is approved, and there is hereby authorized $6,000,000 for initiation and partial accomplishment of the project."

B. REPORTS.

1. A preliminary report on the survey for flood control of the Thames River was submitted to the Chief of Engineers on 14 November 1938. The "Report on Survey for Flood Control, Thames River", dated 22 December 1939 together with the review of the report was submitted later to the Chief of Engineers and was transmitted by the Secretary of War to the 76th Congress as House Document No. 885.

2. In accordance with R&H No. 19, 1939, E.D. 7402 (Construction Program) a "Definite Project Report for the Norwich Channel Improvement, Shetucket River" presenting concise and up-to-date information on the authorized project was submitted June 1944 to the Chief of Engineers . . . . . . . This report was revised and resubmitted in September 1944.

C. NECESSITY FOR THE IMPROVEMENT.

The City of Norwich experienced major floods in March 1936 and September 1938. Several lesser floods had been experienced prior to 1936. Direct damage from the largest flood of record has been estimated at $1,869,000 or approximately five percent of the assessed valuation. Although a large measure of protection will be provided by the seven flood control reservoirs to be built under the comprehensive plan, local channel improvement at Norwich is necessary to assure protection from major floods such as that of September 1938. Such channel improvement is necessarily restricted to improvement of the existing bottom and sides through the critical reach which is confined by structures on both banks.

# II. DESCRIPTION OF AREAS

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### A. SHETUCKET RIVER WATERSHED.

At Norwich, Conn. the Shetucket and Yantic Rivers meet to form the Thames River, a tidal river that flows southerly for fifteen miles through New London, Conn. to Long Island Sound. The Thames River and its tributaries drain an area of 1473 square miles in Connecticut, Massachusetts and Rhode Island. The Thames River watershed lies principally in eastern Connecticut with three of the main tributaries rising in southern Massachusetts and one tributary rising in western Rhode Island.

The Shetucket River, the principal tributary of the Thames River, drains an area of 1264 square miles which is approximately 85 percent of the entire Thames River drainage area. Its watershed is roughly elliptical in shape with its major axis, about fifty-three miles long, lying in a north-south direction and its minor axis, about thirty-eight and a half miles long. lying in an east-west direction. The topography in this area is generally hilly with numerous swamps, mill ponds and reservoirs, with a few natural lakes and ponds. From a maximum of 1280 feet above mean sea level along the northwestern divide the elevations vary to mean sea level at Norwich. Along the three main tributaries to the Shetucket River, and their tributaries, there is a succession of small mill and power dams that develop approximately fifty percent of the river fall into power. The rivers and streams flow southerly to Norwich at the southern end of the watershed. The Thames River watershed is shown on Plate No. 1.

### B. SHETUCKET RIVER - NORWICH, CONN.

The Shetucket River is formed just east of Willimantic, Conn. by the confluence of the Willimantic and Natchaug Rivers. It flows southerly to its confluence with the Quinebaug River, its main tributary, and thence southwesterly through Norwich, Conn. where it meets the Yantic River to form the Thames River.

The river flows in a narrow valley for the major extent of its length to a point about one thousand feet above its mouth where it narrows considerably in passing through a rock gorge. Within this reach, in the principal business area of Norwich, Conn., the restrictions to the river flow are the greatest. The restrictions to flow are four-fold, occurring as an abrupt curve where the width narrows instantly, together with irregular banks partly formed by the abutments of the New Haven R.R. bridge and the Laurel Hill bridge and the irregular riverbed. The channel cross-section is reduced further during high stages by the masonry retaining walls supporting the buildings and railroad tracks constructed adjacent to the waterway on both banks. On the south bank, a branch line of the NYNH&H R.R. runs through a short tunnel under the south approach to the Laurel Hill Bridge and crosses the river on a steel truss bridge at the upstream end of the reach. A transfer track runs from the railroad bridge along the north bank to the Central Vermont R.R. tracks in the western part of the city. The channel width is greatly reduced by the wingwalls and south abutment of the Laurel Hill bridge which are constructed on a section of the rock bank which projects thirty feet more-or-less into the channel. The Norwich Channel Improvement will be centered about this point, extending four hundred feet upstream to the railroad bridge and four hundred feet downstream below the highway bridge. A plan showing the Shetucket River from the Greenville Dam to its mouth is shown on Plate No. II.

## C. <u>FLOODED AREA.</u>

During the flood of September 1938 the business center of Norwich and a large area devoted to industry were inundated by the waters backed up by the channel constriction. The flooded area extended upstream to the Greenville Dam, and included the U. S. Finishing Co. and the Norwich Gas and Electric Co. Many of the larger stores and a theater were flooded with more than six feet of water above the first floor. The same areas have been subject to flooding to a lesser depth by other major floods of record. The maximum predicted flood would result in the flooding of a more extensive area including many residences.

# III. SCHEME OF IMPROVEMENT

## III. SCHEME OF IMPROVEMENT

### A. REQUIREMENTS.

The narrow and constricted channel of the Shetucket River causes the flood discharges to rise to high stages in Norwich resulting in extensive flooding. A system of proposed reservoirs will control 38 percent of the drainage area above Norwich and will provide effective protection against moderate and more frequent floods. The damage which would result from major floods warrants greater protection for the city.

Extensive protection works would be necessary to make the City of Norwich immune to flood damage. This would require the construction of levees and walls. Several plans have been discussed in the "Thames River, Report on Survey for Flood Control" including the enlargement of the present channel by widening and deepening, a bypass tunnel through the rock which forms the constriction, levees and walls, and various combinations of these. As the construction of extensive protection works was found in the above studies to be uneconomical, the improvement will be confined to the enlargement of the channel and will be carried to a degree where adequate protection is assured from all but the maximum floods. The specific design criteria are given in paragraph D of Chapter IV.

### B. EXISTING CONDITIONS.

A part of the city of Norwich, Conn. located on a ridge extending in a north-south direction, forms a natural barrier which forces the Shetucket River to turn northward about two thousand feet from its mouth. A narrow rock gorge, dividing the city near the business center, forms the channel for the river through this ridge.

From the point where the river is turned northward it flows in its normal width of channel along relatively smooth banks for approximately one thousand feet to the New Haven R. R. bridge where it is abruptly turned westward into the narrow rock gorge that has extremely irregular banks and bottom. Just west of the railroad bridge abutment on the left bank of the gorge, the wingwalls and south abutment of the Laurel Hill Bridge project approximately thirty feet into the channel decreasing the channel width at this point. The natural channel width is further reduced, for high stages of the river, by the retaining walls constructed along both banks of the gorge. The sharp bends and insufficient channel section offer great resistance to flood discharges causing the water to rise to high stages, inundating extensive areas of the city. Plate No. III shows the constricted portion of the river and the proposed improvement.

## C. GENERAL SCHEME OF IMPROVEMENT.

The proposed improvement to the Shetucket River in Norwich, Conn. will be the enlargement of its channel cross-section. The improvement will be centered about the Laurel Hill Bridge where the constriction caused by the south abutment will be removed and the channel widened. The channel width cannot be increased at any other point due to the retaining walls along both banks and any further enlargement of cross-section will be confined to an increase in depth.

The channel excavation will not be started until the reconstruction or relocation of the Laurel Hill Bridge has been a ccomplished by local interests. This procedure was recommended in the Report on Survey for Flood Control, Thames River, dated 22 December 1939.

After the bridge work has been completed, the channel cross-section will be increased by removing the constriction on the left bank under the present south abutment and excavating the channel under the bridge to a depth determined by the hydraulic studies. The excavation will be made at rising grades upstream and downstream, terminating in transitions that will grade the proposed widening and deepening into the dimensions of the existing channel. The improvement will extend from the New Haven R.R. bridge downstream for approximately eight hundred feet.

# IV. HYDROLOGY AND HYDRAULICS

## IV. HYDROLOGY AND HYDRAULICS

### A. SCOPE.

Since the Norwich Channel Improvement is designed primarily to operate as an element of the comprehensive plan for flood control in the Thames River Basin it is necessary to consider the hydrology of the whole Thames River Basin and the comprehensive plan for flood control therein in connection with the Norwich Channel Improvement. For this purpose the hydrology contained in the Thames River Survey Report for Flood Control dated 22 December 1939, is considered adequate with respect to the overall effectiveness of the comprehensive plan and its relation to the Norwich Channel Improvement and has accordingly been carried over into this report. Additional details have been added but a complete re-study of the comprehensive plan was not considered necessary.

### B. CLIMATE.

1. Temperatures. - The mean annual temperature of the Thames River Basin is about 48 degrees. Summer temperatures rarely rise to 100°F. Freezing may be expected between the latter part of November and the latter part of March. Over 100 days with temperatures 32°F or below may be expected each year and the temperature may fall below 0°F several times each winter. The average monthly temperatures in the central part of the basin at Storrs, Connecticut, for a period of 48 years ending with 1942 are as follows:

AVERAGE MONTHLY TEMPERATURES AT STORRS, CONN.

| MONTH | DEGREES F. | MONTH | DEGREES F. |
|---|---|---|---|
| January | 25.8 | July | 69.7 |
| February | 25.1 | August | 67.8 |
| March | 34.5 | September | 61.3 |
| April | 45.4 | October | 51.6 |
| May | 56.7 | November | 40.4 |
| June | 64.7 | December | 28.9 |

| | |
|---|---|
| Average annual temperature at Storrs, Connecticut | 47.6 |

2. Precipitation. - a. Average Rainfall. - The mean annual precipitation at Storrs, Connecticut for 53 years of record was 44.31 inches. The maximum annual amount for this same station and period was 66.31 inches in 1938 and the minimum 31.74 inches in 1930. The average annual snowfall at this station is 45.5 inches. The following table summarizes the precipitation record at Storrs by months.

MONTHLY PRECIPITATION AT STORRS, CONNECTICUT

(Depth in Inches)

| MONTH | MEAN | MAXIMUM | MINIMUM |
|---|---|---|---|
| January | 3.64 | 8.52 | 1.05 |
| February | 3.29 | 7.31 | 0.37 |
| March | 4.16 | 10.65 | 0.15 |
| April | 3.43 | 9.51 | 0.70 |
| May | 3.51 | 7.94 | 0.33 |
| June | 3.13 | 9.24 | 0.29 |
| July | 4.28 | 12.24 | 0.84 |
| August | 4.17 | 9.10 | 0.93 |
| September | 3.91 | 17.00 | 0.45 |
| October | 3.55 | 6.83 | 0.15 |
| November | 3.56 | 8.58 | 0.47 |
| December | 3.68 | 9.55 | 1.11 |

Storrs and other rainfall stations in the vicinity of the Thames River Basin are listed on Plate No. VI with their respective periods of record. These same stations are located on the map of the area on Plate No. VII.

b. Storms. - Three types of storms are characteristic of the region in which the Thames River is located, viz. (1) continental storms, (2) hurricanes and (3) thunderstorms. Continental storms may be of the stationary frontal type or rapidly moving intense cyclones, and they are not limited to any season or month but follow one another at more or less regular intervals and with varying intensities throughout the year. The normal path of hurricanes is to the south and east of New England but they may be deflected over this area by continental cyclonic disturbances. They are most likely to occur during the summer and autumn months. Thunderstorms may be of local origin or they may be of the frontal type associated with continental storms during the summer months.

A definite combination of meteorological conditions is recognized as being responsible for most of the great flood-producing storms of the northeastern United States. They are (1) a persistent high-pressure area over the western North Atlantic Ocean, (2) another high pressure area over the central and northern interior of the continent and (3) a low-pressure trough between those "highs" including one or more moving centers. The storm of September 1938, which is the most severe of record over the Thames River Basin and New England, was of this type.

c. Snowfall and Snow Cover. - The average monthly snowfall at Storrs, Connecticut, for 20 years of record is shown in the following table.

AVERAGE MONTHLY SNOWFALL AT STORRS, CONN.

| Month | Depth Inches | Month | Depth Inches |
|---|---|---|---|
| January | 12.7 | September | 0 |
| February | 13.7 | October | 0 |
| March | 6.2 | November | 2.4 |
| April | 2.3 | December | 8.2 |

Average annual snowfall 45.5 inches

Depth of snow cover rarely exceeds 2.0 inches water equivalent for the whole watershed. It is noticeably related to elevation being deeper at the higher elevations. During major flood periods when runoff from melting snow is a significant factor the depth of snow cover rather than degree and duration of melting temperatures will limit the runoff from this source.

C. RUNOFF.

1. General. - Runoff in the Thames River Basin is measured by the United States Geological Survey at the thirteen stations listed below:

| River and Point of Measurement | Drainage Area Square Miles | Years of Continuous Record Ending in 1942 |
|---|---|---|
| Willimantic near South Coventry, Conn. | 121 | 11 |
| Shetucket near Willimantic, Conn. | 401 | 9 |
| Hop near Columbia, Conn. | 76.2 | 10 |
| Natchaug at Willimantic, Conn. | 169 | 12 |
| Mount Hope near Warrenville, Conn. | 29.1 | 2 |
| Quinebaug at Westville, Mass. | 93.8 | 3 |
| Quinebaug at Quinebaug, Conn. | 157 | 11 |
| Quinebaug at Putnam, Conn. | 331 | 13 |
| Quinebaug at Jewett City, Conn. | 711 | 24 |
| Little at Buffumville, Mass. | 27.7 | 3 |
| Five Mile at Killingly, Conn. | 58.2 | 5 |
| Moosup at Moosup, Conn. | 83.5 | 10 |
| Yantic at Yantic, Conn. | 88.6 | 12 |

The locations of these stations are shown on Plate No. VII. The average annual runoff for the years of record is about 51 percent of the precipitation and varies little over the basin. Although notable exceptions have occurred, it is to be expected that the percent of surface runoff from intense storms will be greater than the average annual value of 51 percent, regardless of the season of the year. Runoff records for the Shetucket River near Willimantic and for the Quinebaug River at Jewett City are summarized by months in the following tables:

## MONTHLY RUNOFF, SHETUCKET RIVER NEAR WILLIMANTIC - 401 SQUARE MILES

| Period | Runoff in Inches | | |
|---|---|---|---|
| | Mean | Maximum | Minimum |
| January | 2.76 | 4.97 | 1.42 |
| February | 2.08 | 3.34 | .82 |
| March | 4.70 | 11.36 | 1.98 |
| April | 3.84 | 8.11 | 1.89 |
| May | 2.18 | 3.26 | 1.48 |
| June | 1.52 | 3.22 | .61 |
| July | 1.18 | 5.05 | .37 |
| August | .67 | 1.88 | .29 |
| September | 1.69 | 9.94 | .25 |
| October | 1.14 | 2.38 | .26 |
| November | 1.65 | 4.17 | .57 |
| December | 2.38 | 4.74 | .66 |
| YEAR | 25.79 | 41.05 | 15.31 |

## MONTHLY RUNOFF, QUINEBAUG RIVER AT JEWETT CITY - 711 SQUARE MILES

| Period | Runoff in Inches | | |
|---|---|---|---|
| | Mean | Maximum | Minimum |
| January | 2.29 | 4.53 | .51 |
| February | 1.98 | 3.32 | 1.04 |
| March | 4.16 | 11.24 | 1.98 |
| April | 3.70 | 7.64 | 1.75 |
| May | 2.27 | 3.90 | 1.00 |
| June | 1.46 | 3.44 | .72 |
| July | 1.19 | 6.66 | .39 |
| August | .84 | 2.63 | .24 |
| September | 1.09 | 5.50 | .22 |
| October | .97 | 2.31 | .21 |
| November | 1.48 | 4.56 | .37 |
| December | 2.09 | 4.72 | .46 |
| YEAR | 23.52 | 38.23 | 10.85 |

2. Floods. - a. Historical Floods. - During the past 110 years the Thames River Basin has experienced four localized floods and six great general floods. Of the general floods, two of them, occurring in September 1828 and March 1876, were in turn the greatest floods of record prior to the flood of February 1886. They occurred before the time of extensive industrial development in the Thames Basin, and although data on these two floods are meager, it is known that they did not cause excessive losses.

b. Floods of Record. - (1) February 1886. - The February 1886 flood resulted from an average precipitation of over seven inches of rainfall within a three-day period. Conditions were favorable for a high runoff, and resulted in a flood approximately equal to that of March 1936, in some parts of the watershed.

(2) March 1936. - The March 1936 flood occurred in two peaks. The second and larger peak resulted from an average precipitation of about 5-1/2 inches plus runoff from melting snow. Distribution of this rainfall and the water content of snow is shown on Plate No. VIII. Rainfall and runoff data given in U.S.G.S. Water Supply Paper 798 are tabulated below.

Rainfall, Water Content of Snow and Runoff-March 1936
(Depth in Inches)

| River and Point of Measurement | Drainage Area Sq.Mi. | Precipitation 9-22 March | Water Content of snow 9 March | Runoff |
|---|---|---|---|---|
| Willimantic at South Coventry | 121 | 7.6 | 2.6 | 7.64 |
| Shetucket at Willimantic | 401 | 7.85 | 2.4 | 9.88 |
| Hop at Columbia | 76.2 | 7.0 | 2.1 | 7.05 |
| Natchaug at Willimantic | 169 | 8.55 | 2.5 | 9.48 |
| Quinebaug at Quinebaug | 157 | 9.2 | 3.5 | 10.70 |
| Quinebaug at Putnam | 331 | 9.0 | 3.2 | 10.61 |
| Quinebaug at Jewett City | 711 | 8.1 | 2.6 | 9.42 |
| Moosup at Moosup | 83.5 | 6.85 | 2.2 | 8.26 |
| Yantic at Yantic | 88.6 | 6.65 | 1.5 | 7.29 |

The peak discharge at the Greenville Dam was estimated by the U. S. Geological Survey at 47,600 c.f.s. representing normal runoff. The actual peak resulted from normal runoff augmented by dam failures upstream and has been estimated at 51,500 c.f.s.

(3) <u>September 1938</u>. - The maximum flood of record on the Thames River Basin occurred in September 1938, and resulted from an average rainfall of about ten inches over the entire watershed. With the exception of a few tributaries in the extreme northeastern part of the watershed, the maximum stages of the March 1936 flood were equalled or exceeded. The hurricane of September 21st produced an abnormally high tide along the southern New England coast. In the lower reaches of the Shetucket and Yantic Rivers, the flood occurred almost synchronously with the tidal wave. Distribution of rainfall is shown on Plate No. IX. Rainfall and runoff data given in U.S.G.S. Water Supply Paper 867 are tabulated below.

*Rainfall and Runoff in Inches - September 1938*

| River and Point of Measurement | Drainage Area Sq.Mi. | Precipitation 17-21 Sept. | Runoff |
|---|---|---|---|
| Willimantic at South Coventry | 121 | 14.5 | 8.7 |
| Shetucket at Willimantic | 401 | 14.0 | 7.7 |
| Hop at Columbia | 76.2 | 15.4 | 7.25 |
| Natchaug at Willimantic | 169 | 13.25 | 8.25 |
| Quinebaug at Quinebaug | 157 | 13.25 | 7.2 |
| Quinebaug at Putnam | 331 | 11.7 | 5.4 |
| Quinebaug at Jewett City | 711 | 8.9 | 4.3 |
| Five Mile at Killingly | 58.2 | 7.35 | 2.4 |
| Moosup at Moosup | 83.5 | 4.55 | 1.15 |
| Yantic at Yantic | 88.6 | 10.7 | 7.9 |

According to the U. S. Geological Survey the average infiltration index for this storm was 0.13 inch per hour. The peak discharge at the Greenville Dam, approximately two miles upstream from the center of Norwich, was estimated by the United States Geological Survey at 77,700 c.f.s. Prior to publication of this estimate, the Providence District, U. S. Engineer Department, had estimated the discharge at 75,000 c.f.s., which value has been used in this design.

c. Maximum Predicted Flood. - The maximum predicted flood used in connection with the design of the Norwich Channel Improvement is that derived for the Thames River Report on Survey for Flood Control dated 22 December 1939 and is discussed therein as follows:

> "The flood of September 1938 was the greatest flood on the Thames River Basin during the period of record. However, the floods of February 1886, March 1936 and July 1938 were higher in some short reaches. A greater flood than any of these would occur on the Thames River Basin if a storm equal to some which have occurred in the region should center over the watershed at a time when conditions were favorable to a high runoff. The maximum predicted flood at points in the Thames Basin has been computed, as follows:
>
> "a. The rainfall volume used equals the maximum total rainfall which occurred during the storm of September 1938 on an area equal to the drainage area involved. This storm is the maximum storm of record in New England.
>
> "b. It was assumed that the entire rainfall occurred in 48 hours.
>
> "c. The rainfall distribution was assumed to be proportional to that determined by the United States Weather Bureau in a recent study of rainfall in New England.
>
> "d. An infiltration rate of only .05 inches per hour was used.
>
> "e. Computations for all points upstream from and including Putnam and Willimantic were made by the use of unit graphs.
>
> "f. For points downstream from Putnam and Willimantic, the maximum predicted flood was computed by routing from these points and adding tributary and local inflow based

on unit graphs. The resulting runoff volume of the maximum predicted flood at these points varies from 11.64 to 13.73 inches, which is equivalent to a runoff factor of approximately 85 percent. The duration of the flood varies from 4 to 7-1/2 days. At Norwich, the maximum predicted flood has a peak discharge of 172,000 cubic feet per second with a probable frequency of occurrence of once every 1600 years. This discharge is over twice as large as the maximum flood of record, 75,000 cubic feet per second in September 1938."

According to Hydrometeorological Report No. 1 which was completed after the Thames River Survey Report the maximum possible rainfall on the Thames River Basin is 14.4 inches in 48 hours which after making allowances for infiltration at 0.05 inch per hour leaves a rainfall excess of 12.60 inches. Since this is less than 8% larger than the rainfall excess used a re-computation of the maximum predicted storm was not considered necessary.

D. BASIS OF PROJECT DESIGN.

1. Criteria. - The Norwich Channel Improvement is designed primarily to operate as an integral part of the comprehensive plan for flood control in the Thames River Basin. Its function in this plan is to provide local protection at Norwich in addition to that provided by the seven reservoirs of the comprehensive plan.

Full protection against the maximum predicted flood, even that modified by the proposed reservoirs, it not economically feasible. The project is accordingly designed to satisfy the following criteria.

a. Full protection against a recurrence of the maximum flood of record with the channel improvement and the seven reservoirs in operation.

b. With the channel improvement and the seven reservoirs in operation the stage of the maximum predicted flood shall be approximately Elevation 22.5 at the railroad bridge as shown on Appendix Plate No. 23 of the "Report on Survey for Flood Control, Thames River", dated 22 December 1939.

c. A recurrence of the maximum flood of record after improvement of the channel but before completion of the reservoirs shall cause only minor damages.

2. Flood Magnitudes Considered. - The peak discharges of the floods considered in the design of the Norwich Channel Improvement are as follows:

September 1938 flood (actual occurrence) Q = 75,000 c.f.s.

September 1938 flood modified by 7 reservoirs Q = 31,000 c.f.s.

Maximum predicted flood under existing conditions Q = 172,000 c.f.s.

Maximum predicted flood modified by 7 reservoirs Q = 112,000 c.f.s.

Hydrographs of the September 1938 flood and the maximum predicted flood at Norwich, with and without modification by reservoirs are shown on Plates Nos. X and XI.

3. Design Details. - a. Effect of Tide. - Mean high water at New London is 2.6 feet above mean low water or approximately 1.3 feet above mean sea level. This elevation of mean high water is 0.1 foot higher than that shown on Plate No. XII and is taken from a more recent determination. At Norwich, 15 miles upstream, mean high water due to tidal action is 1.8 feet above mean sea level. For approximately 98% of the time, flow in the Shetucket River is so small that high tide at Norwich is 3.5 feet above mean sea level or lower. However, this is not true for freshet conditions in the river when stages at the mouth of the Shetucket River are controlled by backwater in the Thames River. Tide levels at New London affect these stages for discharges up to about 75,000 c.f.s.

b. Shetucket River Tailwater. - During the September 1938 hurricane, the tide at New London rose to 8.4 feet above mean sea level. The corresponding stage at Norwich was 14.7 feet above mean sea level. The drop in water surface elevation from Norwich to New London was 6.3 feet in 15 miles or approximately 0.4 foot per mile. This high tide and the corresponding peak stage at the mouth of the Shetucket River were very nearly synchronized with the peak discharge of the Shetucket River which was 75,000 c.f.s. A study of flow in the Thames River determined that the stage at the mouth of the Shetucket River must be 13.0 feet above mean sea level when the Shetucket River discharges 75,000 c.f.s. and the tide at New London is within its normal range of 1.3 feet above to 1.3 feet below mean sea level.

Note: - Addenda dated June 1945 and September 1945 include summaries of computations to establish this freshet stage-discharge relation, and are inserted herein following the Photographs (see index of plates, Page 25).

Tidal observations of limited extent made during the period 18-20 June 1917 established that when the tide was 1.3 feet above mean sea level at New London, it was 1.8 feet above mean sea level at Norwich. The mean discharge during this period was not recorded because there were no gaging station records at that time. However, Connecticut River discharges for the same period are known. Comparison of simultaneous records for the Shetucket and Connecticut Rivers in May and June of 1940 and 1942 when general runoff conditions of both rivers were alike, made possible the determination by analogy of the Shetucket River discharge of 18-20 June 1917 as 2,610 c.f.s.

From these data, two points on the Shetucket River tailwater rating curve were established, viz.:

Q = 75,000 c.f.s. at El. 13.0 m.s.l.
Q = 2,610 c.f.s. at El. 1.8 m.s.l.

These points were plotted logarithmically and the entire rating curve was developed from this plot. The rating curve is shown on Plate No. II.

c. Derivation of Loss Coefficients. - The only flood profile observations available were those made in September 1938 when the discharge was 75,000 c.f.s. Values of Manning's "n" that included the effects of all flow conditions were developed for this flood. Water surface profiles for Q = 75,000 c.f.s. were computed for tailwater elevations of 14.7 and 13.0, which reflected the same flood conditions, existing channel conditions, and hurricane tide conditions and normal tide conditions respectively at New London. The data so established were used to compute the loss coefficients as described below. Since the proposed channel improvement lies entirely downstream from the railroad bridge, computations for the breakdown of losses were restricted to the reach affected by the design. Losses were considered to be composed of three parts, viz.: friction loss, bend loss and eddy loss due to expansion or contraction of the water areas.

The total bend loss between the railroad bridge and Laurel Hill Bridge was assumed to be equal to 20% of the net change in velocity head between these sections. (Total change in direction equals 84 degrees.) This value amounted to approximately 30% of the average velocity head through the bend and this evaluation of bend losses was used in all subsequent studies since the proposed improvement does not change the existing channel alinement.

Eddy losses were computed as contraction loss = $K_1 \Delta h_v$, and expansion loss = $K_2 \Delta h_v$. Friction losses were computed by the Manning formula. The relations between $K_1$, $K_2$ and Manning's "n" were computed for various assumed values of $K_1$ and for Q = 75,000 with tailwater at Elevation 14.7 and 13.0. The combination that gave the closest agreement in values of "n" was adopted.

Final formulas for losses are listed below:

| | | |
|---|---|---|
| Friction loss | - | "n" = 0.044 |
| Bend loss | - | $h_b = 0.30\ \overline{h}_v$ |
| Contraction loss | - | $h_c = 0.06\ \Delta h_v$ |
| Expansion loss | - | $h_e = 0.83\ \Delta h_v$ |

where $\overline{h}_v$ = average velocity head between the railroad bridge and Laurel Hill Bridge and $\Delta h_v$ = change in velocity head between sections.

d. Superelevation. - Actual observation of the September 1938 flood at Norwich disclosed no definite ride up of water in the existing channel. There were extreme turbulence, splash, standing waves diagonally part way across the river, and surges about four feet high which attacked both banks alternately. The high water marks on which the computed water surface profiles are based were well back from the bank of the river and well distributed in location for check purposes. It is considered that the computed profiles are correct within practicable limits of accuracy. No special allowance for superelevation is considered necessary. The improved channel will retain its present awkward alinement since it is not feasible to change it. Much of the turbulence observed under existing conditions will remain, and for the maximum floods the obstruction offered by the underside of the railroad bridge at the beginning of the sharp bend in the river will preclude the formation of any definite tendency to superelevation of the water surface around the outside of the bend.

e. Improvement Studies. - Only minor changes in the plan of improvement proposed in the Thames River Report on Survey for Flood Control are necessary. The principal changes are the result of further foundation investigations. These investigations indicate that no rock excavation should be made within ten feet of an existing or proposed structure because of the poor condition of the masonry retaining walls and the rock upon which they are founded. The alinement adopted therefore represents the maximum usable width consistent with the foregoing requirement. The problem is thus reduced to determining the most satisfactory bottom profile. In order to eliminate the large expansion losses which occur under existing conditions, the low point in the bottom profile must be under the Laurel Hill Bridge. Various elevations at this point and various grades above and below were studied. The adopted plan best satisfied the design criteria and is as follows:

Bottom Profile: Level at El. - 32.0 under Laurel Hill Bridge (Sta. 5 + 75 to Sta. 6 + 15); rising on 3.25% downstream from Sta. 5 + 75 and 4.80% upstream from Sta. 6 + 15. Estimated volume of excavation: 36,000 c.y.

Water surface profiles extending upstream to the U. S. Finishing Co. were developed for this plan for the following flood discharges:

1. Maximum predicted flood reduced by the seven reservoirs of the comprehensive plan - Q = 112,000 c.f.s.

2. Maximum flood of record reduced by the seven reservoirs of the comprehensive plan - Q = 31,000 c.f.s.

3. Maximum flood of record with no reservoirs in operation - Q = 75,000 c.f.s.

General plans, profiles, and cross sections of the adopted plan are shown on Plates Nos. II, III, and XIII through XVIII. Rating curves at the railroad bridge and at the U. S. Finishing Company are shown on Plates Nos. IV and V. Water surface elevations at the railroad bridge are given in the following table for normal tide conditions at New London. For the 1938 flood and hurricane tide condition the water surface elevation at the railroad bridge was the same as that shown in the table for 75,000 c.f.s. in the existing channel.

| Flood | Conditions | Q-c.f.s. | El. of W. S. at RR Bridge |
|---|---|---|---|
| 1938 | No reservoirs; Existing Channel | 75,000 | 23.3 |
| | No reservoirs; Improved Channel | 75,000 | 16.1 |
| | 7 reservoirs; Existing Channel | 31,000 | 11.1 |
| | 7 reservoirs; Improved Channel | 31,000 | 8.6 |
| Maximum Predicted | 7 reservoirs; Existing Channel | 112,000 | 32.0 |
| | 7 reservoirs; Improved Channel | 112,000 | 23.4 |

<u>NOTE:</u> - Shetucket River backwater computations for a discharge of 75,000 c.f.s. are included in Addendum II. (See index of plates, page 25.)

# V. PROPOSED CHANNEL IMPROVEMENT

## V. PROPOSED CHANNEL IMPROVEMENT

### A. SCOPE.

The proposed improvement to the channel of the Shetucket River at Norwich, Connecticut consists entirely of rock excavation starting at the New Haven R.R. bridge and extending downstream for approximately eight hundred feet. The project will be centered at the point where the centerline of the existing Laurel Hill Bridge intersects the channel centerline at Sta. 6+00.

The channel width will be increased under the bridge between Sta. 5+80 and Sta. 6+20, to 108 feet and will be excavated to 32.0 feet below Mean Sea Level. The width of the excavation will increase from 108 feet, at Sta. 6+20 at the highway bridge, to 138 feet near the railroad bridge upstream and the channel bottom will be excavated on a rising grade as shown on Layout Plan Plate No. XIII. From 108 feet, at the highway bridge at Sta. 5+80, the width of excavation will be gradually increased to 132 feet at a point approximately two hundred feet downstream and will be excavated on a rising grade as shown on Layout Plan Plate No. XIII. At the points where the rising grades of the bottom excavation intersect the existing bottom, transitions will be made grading the widening and deepening into the existing channel. The use of fifty foot chords to define the side limits will facilitate the drilling. The locations and profiles of the side limits of the proposed channel excavation are shown on Plates Nos. III and XIII. The alignment of the side limits of excavation are so-placed as to establish a minimum clearance of ten feet between them and the existing masonry retaining walls on the banks. This is necessary due to the poor condition of the retaining walls and their jointed and fractured rock foundation. Any great disturbance of this rock foundation, such as might be caused by blasting close to the walls, might possibly weaken them or cause their failure.

### B. EXCAVATION PROCEDURE.

The proposed scheme of procedure for the channel improvement will be the repetition of drilling, blasting and dredging of the rock, starting at the channel centerline and working toward both shores. The side limits of the excavation along the banks will be close-drilled with vertical holes spaced not more than one foot on centers. An extensive system of range lines will be provided for the control of the alignment of these side limits, which will be tied into the present survey traverse and coordinate points, as shown on Plate No. XIII.

The first operation will start on or near the channel centerline where the rock will be drilled and blasted to open a slot approximately twenty-five feet wide and to the final depth required. All of the rock loosened by the blast will be removed before the work progresses toward the shore. The next line of holes will then be drilled and blasted toward the open face made by the slot in the previous operation. All of the loosened rock will be removed before the above process is repeated. The work will then progress toward the shore working to the full channel depth at each step. A series of datum points will be maintained on the shores for reference in depth control. These will be necessary as the drilling of the holes will be made from drill-boats that will be working in water depths of ten to twenty feet and subjected to the tidal action of the river. The blasting will be limited to light charges to prevent damage to nearby structures, property and the public. Experiments will be conducted to determine the spacing and the depth of the holes and the amount and type of dynamite that can be safely used. The line of close-drilled holes along the side limits of the excavation will not be charged with dynamite. But, as the excavation approaches the side limits, the spacing of holes and charges of dynamite will be made in such a manner as to cause the rock to break along the limit line without disturbing the adjoining structures. The rock and other materials or debris excavated will be spoiled on approved dumping grounds. Two privately-owned dumping grounds are located on the east bank of the Thames River approximately four miles downstream. The New London Public Dumping Ground is located approximately 18.6 miles from the site in Long Island Sound.

The quantity of rock excavation is estimated at 34,000 cubic yards with an additional allowance of 3,000 cubic yards for over-breakage. This estimate is based on soundings taken on a 10' x 50' grid with one foot allowed for over-breakage. It is estimated that the entire project can be completed during one construction season.

# VI. SUMMARY OF COST

## VI. SUMMARY OF COST

The proximity of the commercial center of Norwich and the railroads along both river banks, limiting the blasting operation to light charges and close-drilling, have been considered in the unit cost of the channel improvement. The cost estimate has been increased 10% for contingencies and 15% for engineering and overhead.

The cost for the lands, easements and rights-of-way and legal expenses thereof, together with the cost of moving or reconstruction of the highway bridge will be borne by local interests.

### ESTIMATE OF COST

| Item | Quantity | Unit | Unit Cost | Amount |
|---|---|---|---|---|
| Rock excavation, dredging | 34,000 | c.y. | $13.00 | $442,000 |
| Rock excavation, overbreakage | 3,000 | c.y. | 6.00 | 18,000 |
| Close-drilling | 31,500 | Lin.Ft. | 3.00 | 94,500 |
| | | | | $554,500 |
| Contingencies 10% | | | | 55,500 |
| | | | | $610,000 |
| Engineering & Overhead 15% | | | | 91,000 |
| TOTAL . . . . . . . . . . . . . . . . . . . . . . | | | | $701,000 |

# VII. CONCLUSIONS

## VII. CONCLUSIONS

A. GENERAL. - It is not possible to protect the lower part of Norwich near the mouth of the Shetucket River against major floods by means of this channel improvement because stages in this area are controlled by backwater from the Thames River. However, as outlined below, the comprehensive plan will provide the principal business center of Norwich with complete protection against the maximum flood of record which has a frequency of occurrence of one in 150 to 200 years.

Some benefits in the form of stage reductions will be realized at the U. S. Finishing Company (Mile 1.6), but the stage of the maximum flood of record modified by the entire comprehensive plan will still be about 4 feet above the stage of zero damage.

B. PROTECTION AGAINST RECURRENCE OF THE MAXIMUM FLOOD OF RECORD. - At a discharge of 75,000 c.f.s. (equal to the September 1938 flood with no reservoirs in operation) there will be a freeboard of about 3 feet against entry of water into the business center of Norwich. However, there will be sufficient water in City Landing to damage the Palace Theater and other buildings on this street. This damage probably could be eliminated by temporary closure such as sandbags. The N.Y., N.H. & H. R.R. track and the transfer track on the right bank will be under 3 to 5 feet of water.

At a discharge of 31,000 c.f.s. (equal to the September 1938 flood modified by seven reservoirs) the freeboard against entry of water into the business section of Norwich will be about 10 feet and there will be a freeboard of about 5 feet against entry of water into City Landing. Freeboard for the railroad transfer track will vary from zero at the mouth of the river to 6 feet near the railroad bridge. The same or greater freeboard is maintained for the railroad upstream from the railroad bridge.

C. PROTECTION AGAINST THE MAXIMUM PREDICTED FLOOD. - At a discharge of 112,000 c.f.s. (maximum predicted flood modified by seven reservoirs) the river stage at the railroad bridge will be the same as that which accompanied the September 1938 flood. Without the operation of reservoirs, the channel improvement is ineffective against the maximum predicted flood (Q = 172,000 c.f.s.) which is 129% greater than the maximum flood of record and which has a probable frequency of occurrence of once in 1600 years.

D. SUMMARY. - The adopted plan provides maximum feasible protection against the maximum flood of record both before and after modification by the seven reservoirs, and reduces the stage of the maximum predicted flood modified by seven reservoirs to within one foot of the stage required by criterion b. This elevation is within the limits of accuracy of the computations because considerable variation in stage due to surges is expected. (See paragraph D-1 on page 17.)

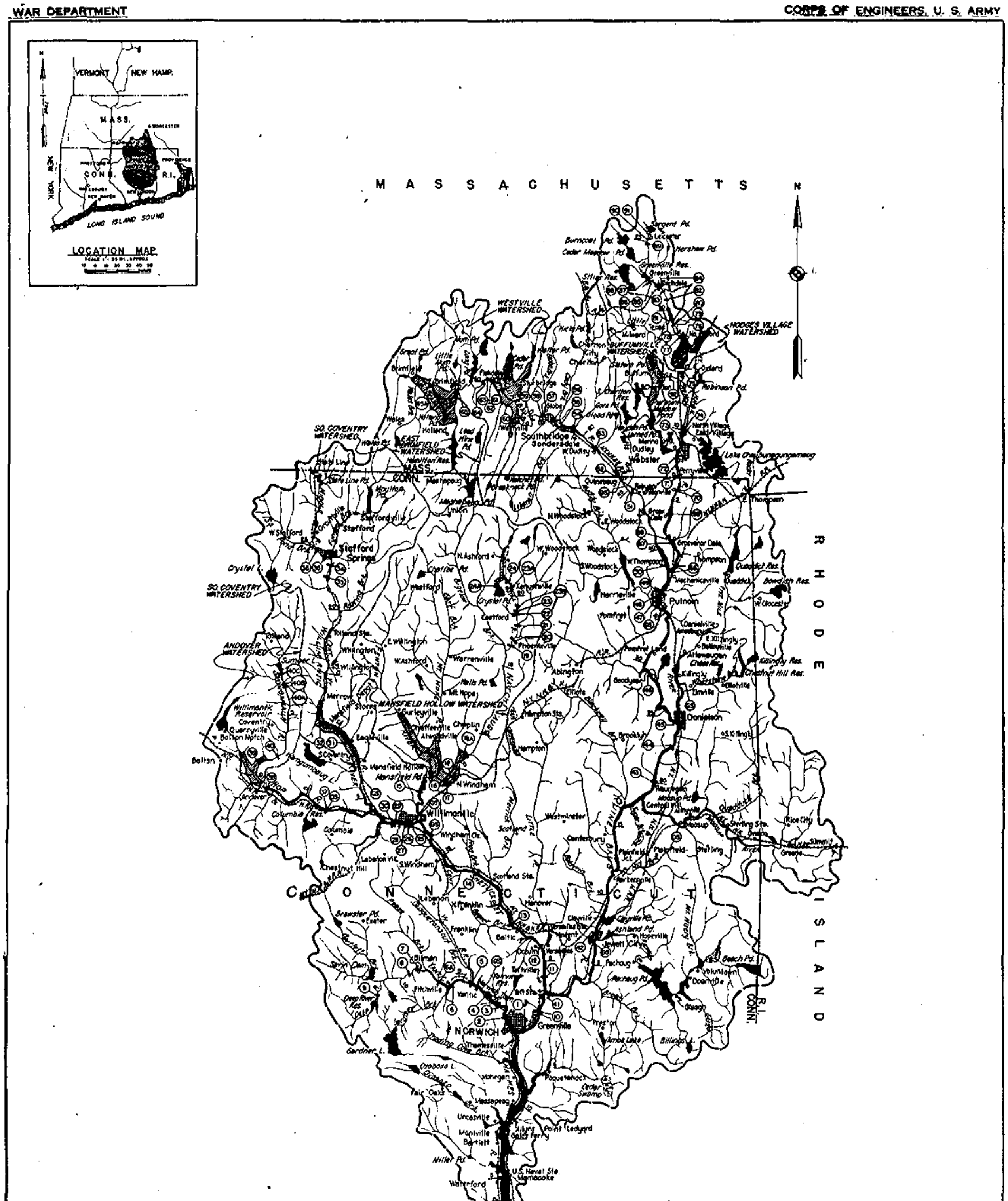
The foregoing statements are based on analysis of all available data. A check of these results by a model study probably could be made if required.

# VIII. INDEX OF PLATES

## VIII. INDEX OF PLATES

WAR DEPARTMENT

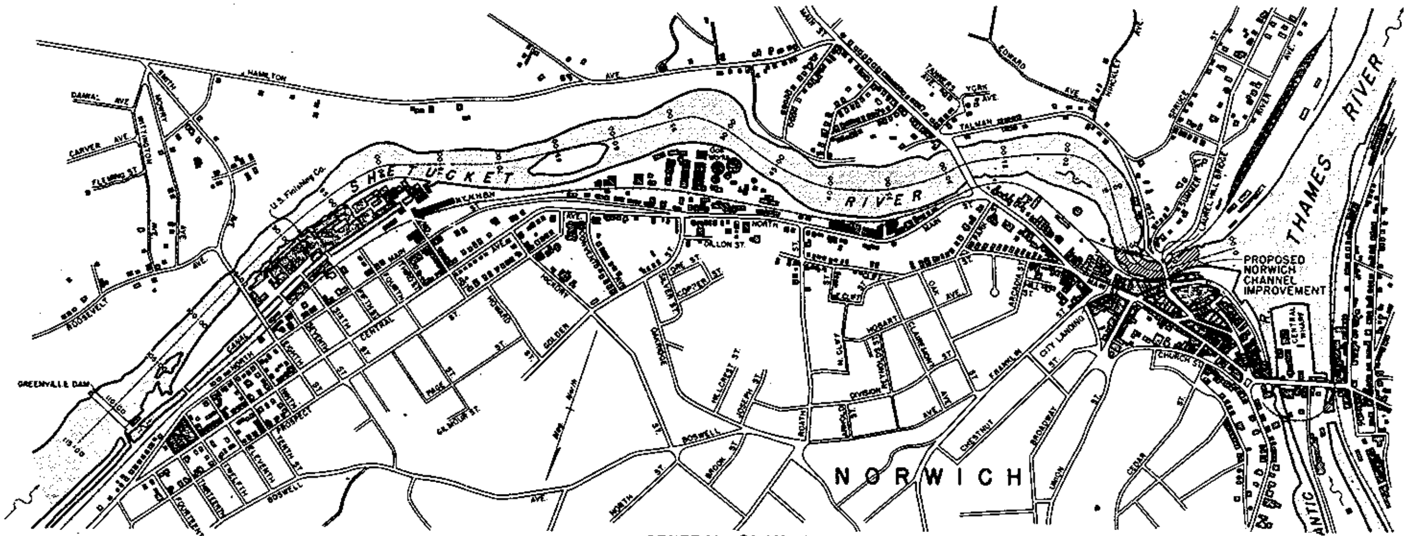
CORPS OF ENGINEERS, U. S. ARMY




A OF D NW-1 PLATE NO. I

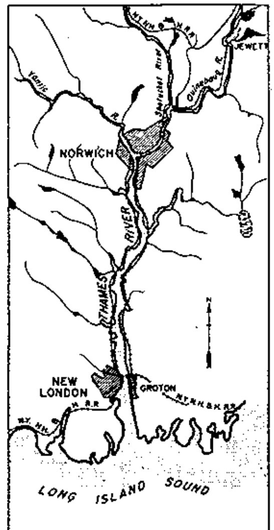
WAR DEPARTMENT

CORPS OF ENGINEERS, U. S. ARMY



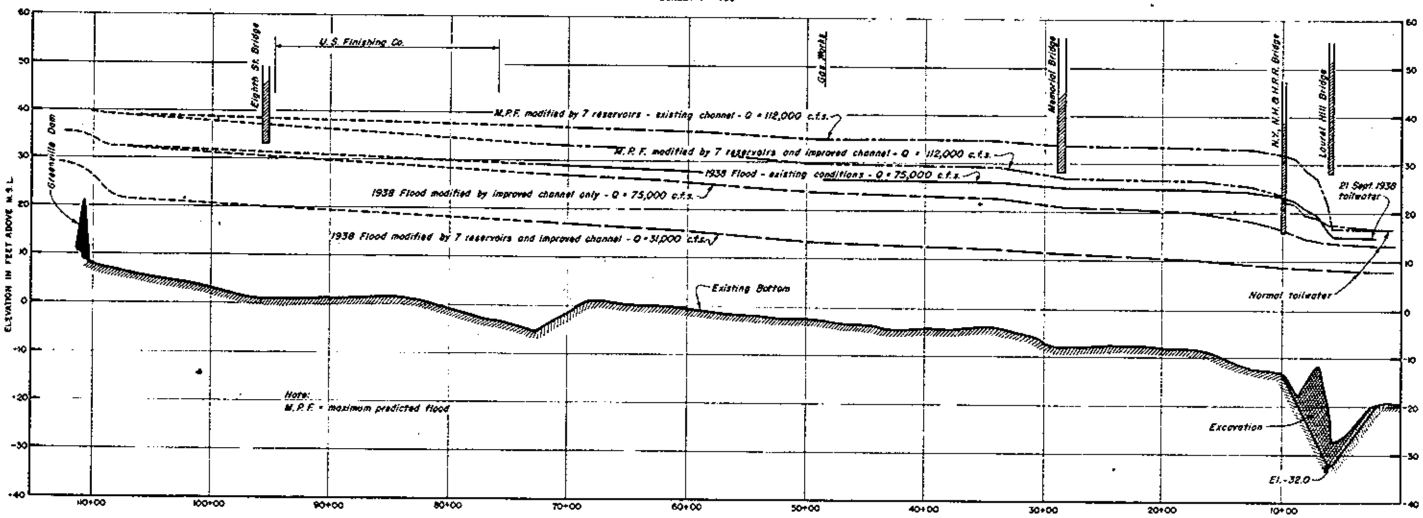

GENERAL PLAN △

SCALE: 1" = 400'



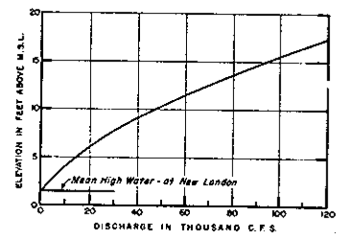

LOCATION MAP

SCALE: 1 : 150,000




PROFILE OF SHETUCKET RIVER FROM GREENVILLE DAM TO MOUTH △

SCALE: HOR., 1" = 400'
VERT., 1" = 10'




RATING CURVE
MOUTH OF SHETUCKET RIVER, NORWICH, CONN.

NOTE:
Plan from U.S.E.D. Plane Table Survey of 1939 and from Aerial Photographs of 1939

| KEY | DATE | REVISION (Indicated by △) | REV. BY | CK. BY | AP. BY |
|---|---|---|---|---|---|
| △ | Mar. '45 | General revisions made and rating curve added | F.C.T. | | |

THAMES RIVER FLOOD CONTROL
NORWICH CHANNEL IMPROVEMENT
PLAN AND PROFILE
GREENVILLE DAM TO MOUTH
SHETUCKET RIVER — CONNECTICUT

IN SHEETS — SCALE: IN. = 400 FT. — SHEET NO.

U. S. ENGINEER OFFICE, PROVIDENCE, R. I. JUNE 1944

SUBMITTED: SENIOR ENGINEER, PROJECT ENGINEER
APPROVAL RECOMMENDED: HEAD ENGINEER, CHIEF, ENGINEERING DIV.
APPROVED: COL., CORPS OF ENGINEERS, DISTRICT ENGINEER

COMPILED: SENIOR ENGINEER
DRAWN: M.H., F.T.
TRACED: W.E.L.
CHECKED:
FILE NO. TH-10-1000

A. OF D. NW-I PLATE NO. II

WAR DEPARTMENT

CORPS OF ENGINEERS, U. S. ARMY

A. OF D. NW-1

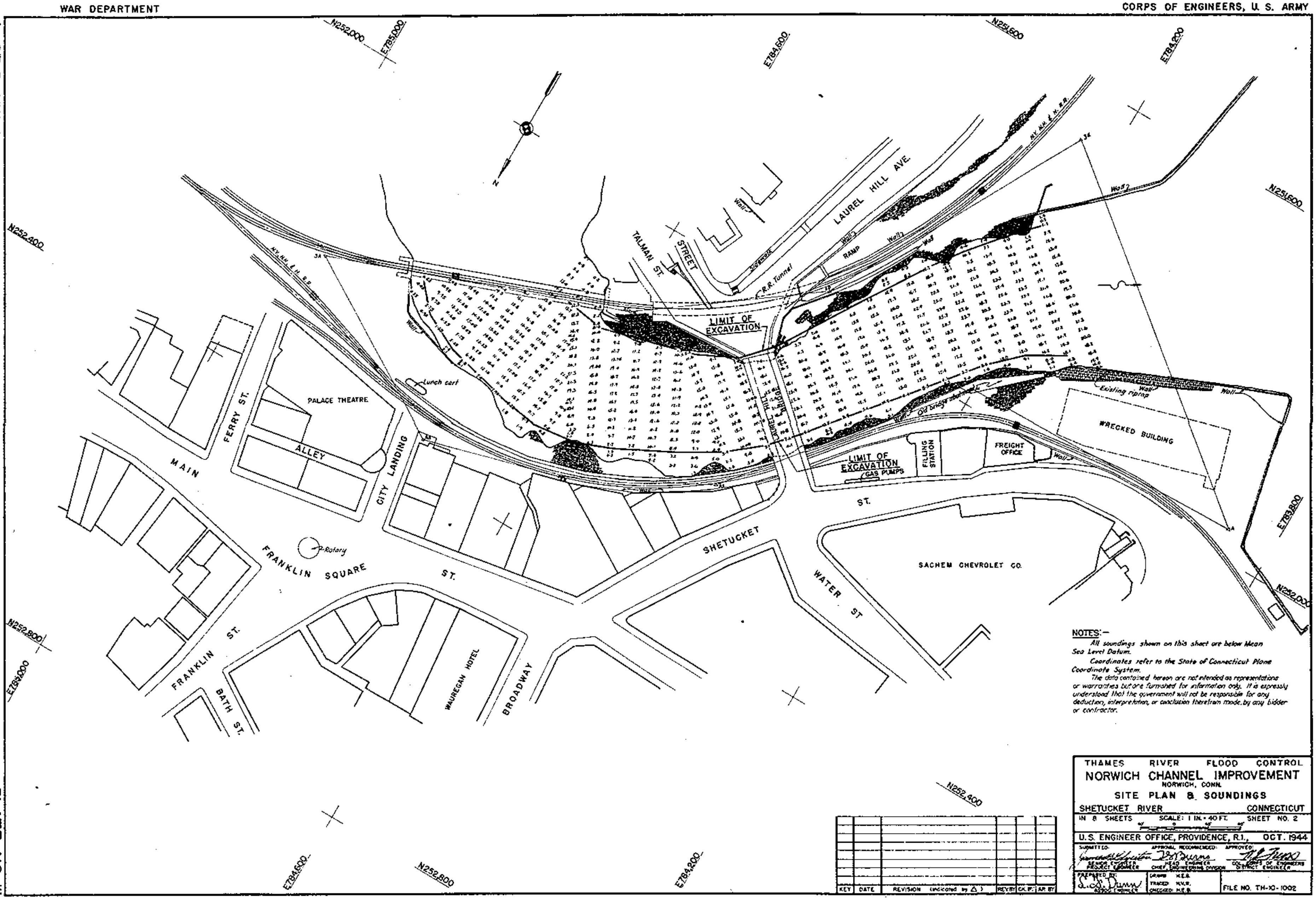
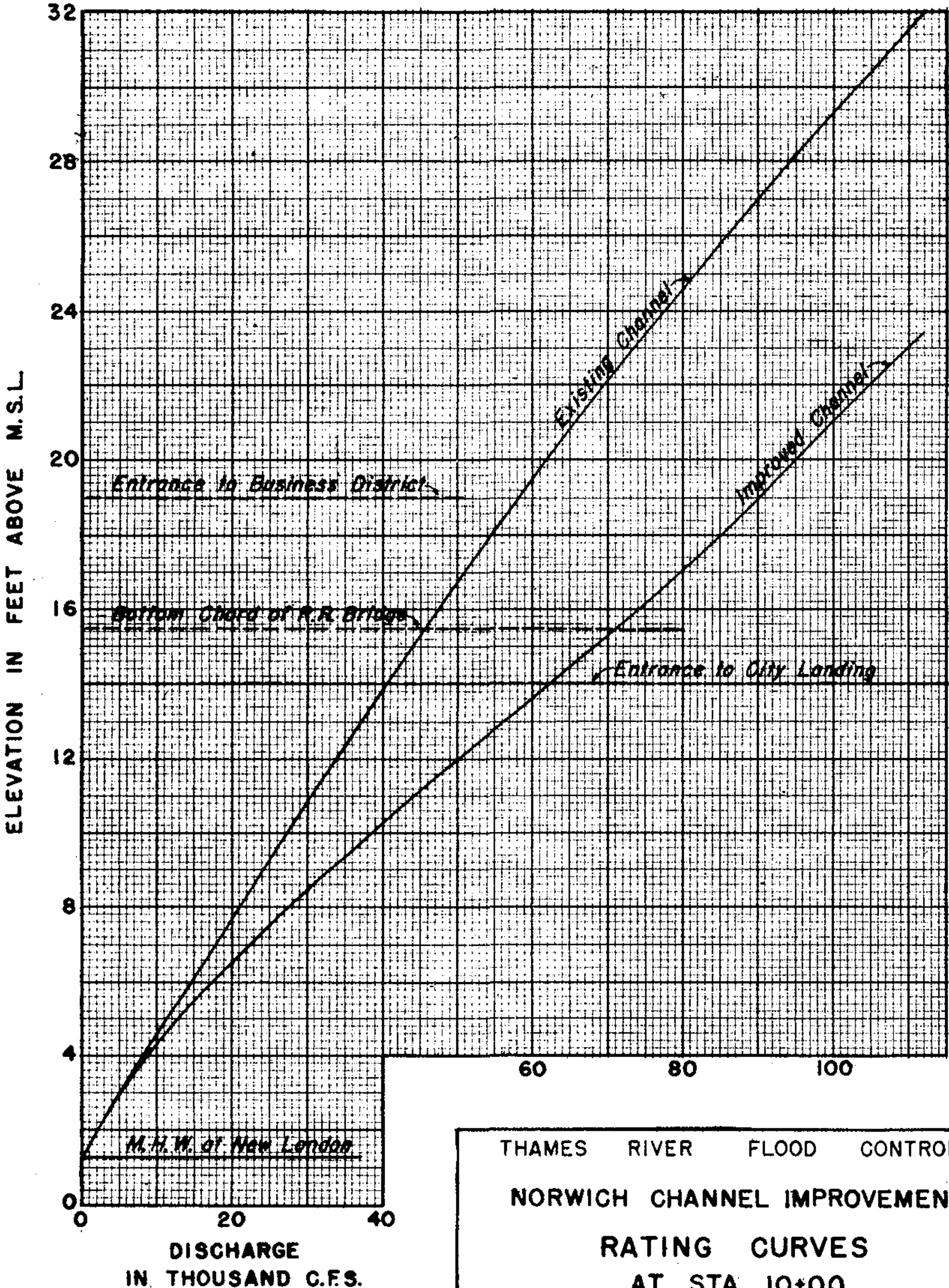



PLATE NO. III




THAMES RIVER FLOOD CONTROL

NORWICH CHANNEL IMPROVEMENT

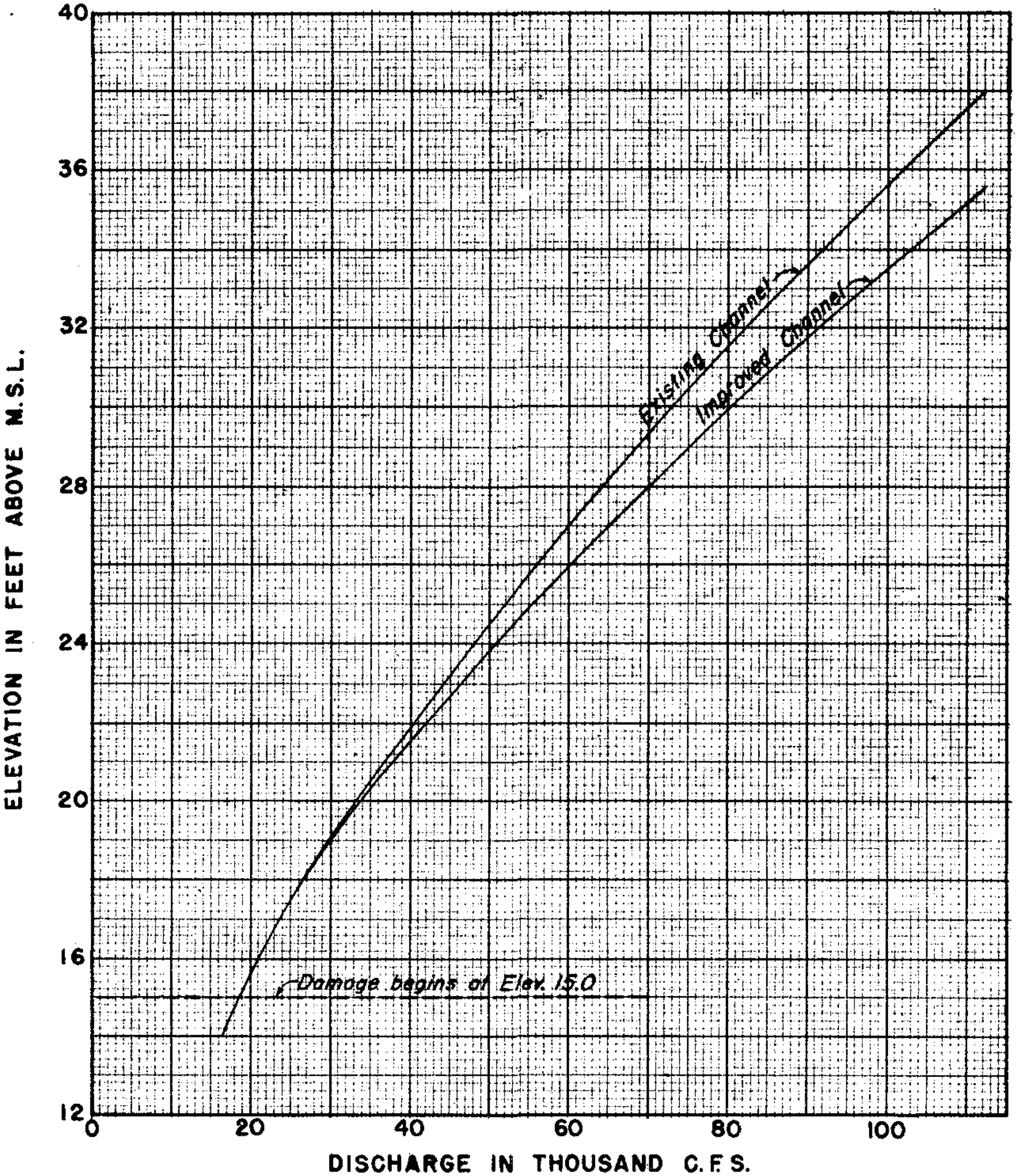
RATING CURVES
AT STA. 10+00
(RAILROAD BRIDGE)

SHETUCKET RIVER CONNECTICUT

U. S. ENGINEER OFFICE PROVIDENCE, R. I.

APRIL 1945

A. OF D. NW-1 PLATE NO. IV




THAMES RIVER FLOOD CONTROL

NORWICH CHANNEL IMPROVEMENT

**RATING CURVES**

**AT STA. 85+00**

(U. S. FINISHING CO.)

SHETUCKET RIVER — CONNECTICUT

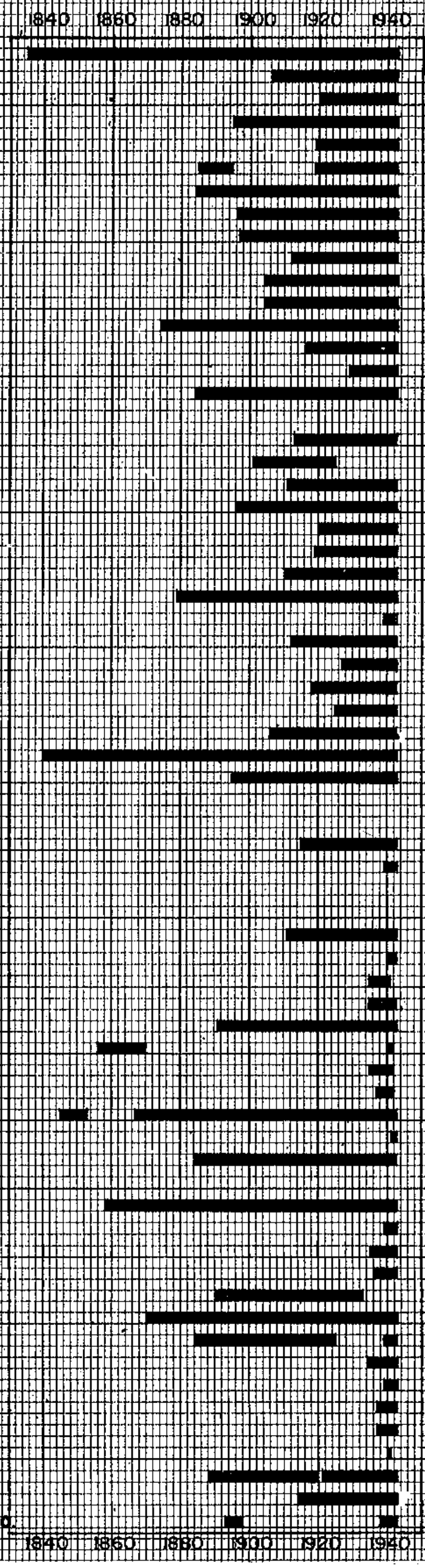
U.S. ENGINEER OFFICE — PROVIDENCE, R. I.

APRIL 1945

A. OF D. NW-1 — PLATE NO. V

| STATION | OPERATED BY |
|---|---|
| **MASSACHUSETTS** | |
| Amherst | Mass State College |
| Ashley Pond | City of Holyoke |
| Bondsville | Boston Duck Co. |
| Boylston | Met. Dist. Water Supply Comm. |
| Charlton Depot | Mass. Dept. of Public Health |
| Hardwick | Mass. Dept. of Public Health |
| Holden No. 2 | City of Worcester |
| Holyoke | Holyoke Water Power Co. |
| Jefferson | Met. Dist. Water Supply Comm. |
| Kendall Reservoir | City of Worcester |
| Kettle Brook No. 3 | City of Worcester |
| Ludlow Reservoir | City of Springfield |
| Lynde Brook | City of Worcester |
| Mc Lean Reservoir | City of Holyoke |
| Millbury | N.E. Power Service Co. |
| Monson | Mass. Dept. of Public Health |
| New Braintree | Mass. Dept. of Public Health |
| Provin Mt. Reservoir | City of Springfield |
| Rutland | Mass. Dept. of Public Health |
| Southbridge | Mass. Dept. of Public Health |
| Springfield | City of Springfield |
| Ware | Mass. Dept. of Public Health |
| Ware Center | Mass. Dept. of Public Health |
| Warren | Town of Warren |
| Webster | Mass. Dept. of Public Health |
| West Brimfield | U.S. Weather Bureau (Coöp.) |
| West Brookfield | Mass. Dept. of Public Health |
| West Rutland | Met. Dist. Water Supply Comm. |
| West Ware | Mass. Dept. of Public Health |
| Westfield Sanatorium | Mass. Dept. of Public Health |
| Whiting St. Reservoir | City of Holyoke |
| Worcester | Clifford L. Davis |
| Worcester Sewage Plant | City of Worcester |
| **RHODE ISLAND** | |
| Hopkins Mills | City of Providence |
| Wood River Jct. | U.S. Weather Bureau (Coöp.) |
| **CONNECTICUT** | |
| Baltic | Baltic Mills Co. |
| Brooklyn | U.S. Weather Bureau (Coöp.) |
| Camp Buck | Conn. State Forestry Dept. |
| Cockaponset Forest | Conn. State Forestry Dept. |
| Colchester | U.S. Weather Bureau (Coöp.) |
| Columbia | U.S. Weather Bureau (Coöp.) |
| Ellington | Soil Conservation Service |
| Enfield | Soil Conservation Service |
| Hartford | U.S. Weather Bureau |
| Jewett City (near) | Jewett City Water Co. |
| Lake Konomac | City of New London |
| Manchester | Manchester Water Co. |
| Middletown | City of Middletown |
| Moodus Reservoir | U.S. Weather Bureau (Coöp.) |
| Natchaug Forest | Conn. State Forestry Dept. |
| Newington | City of Hartford |
| North Grosvenor Dale | Grosvenor Dale Co. |
| Norwich | City of Norwich |
| Pachaug Forest | U.S. Weather Bureau (Coöp.) |
| Putnam | Civil Aeronautics Authority |
| Putnam Heights | U.S. Weather Bureau (Coöp.) |
| Shenipsit Forest | Conn. State Forestry Dept. |
| South Meadows | City of Hartford |
| Staffordville | U.S. Weather Bureau (Coöp.) |
| Storrs | U.S. Weather Bureau (Coöp.) |
| Thompsonville | Conn. Light and Power Co. |
| Windsor | Conn. Agricultural Experiment Sta. |

PERIOD OF RECORD

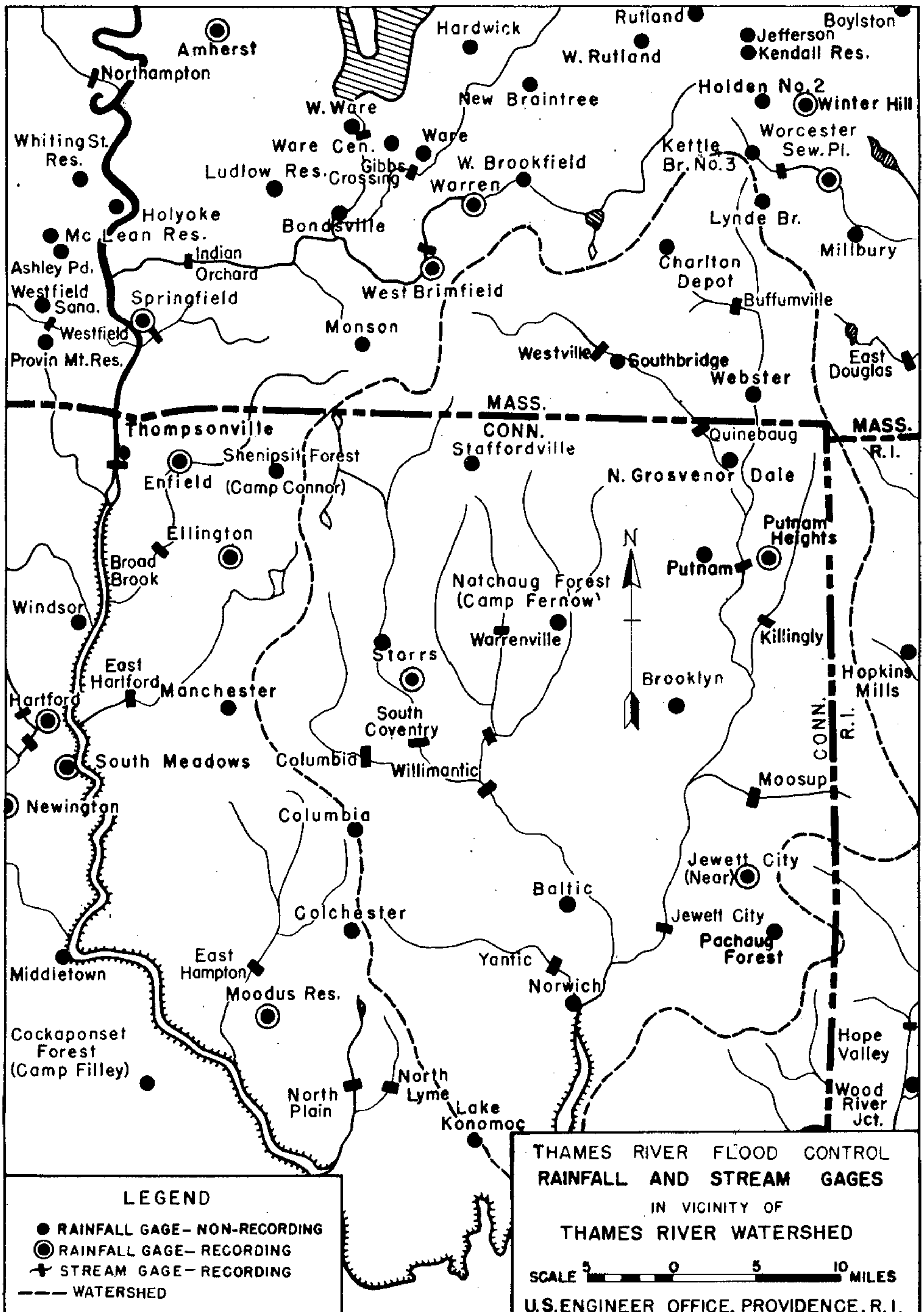



THAMES RIVER FLOOD CONTROL

LENGTH OF RECORD OF RAINFALL STATIONS IN VICINITY OF THAMES RIVER WATERSHED

U.S. ENGINEER OFFICE PROVIDENCE, R. I.

A. OF D. NW-1 PLATE NO. VI




THAMES RIVER FLOOD CONTROL

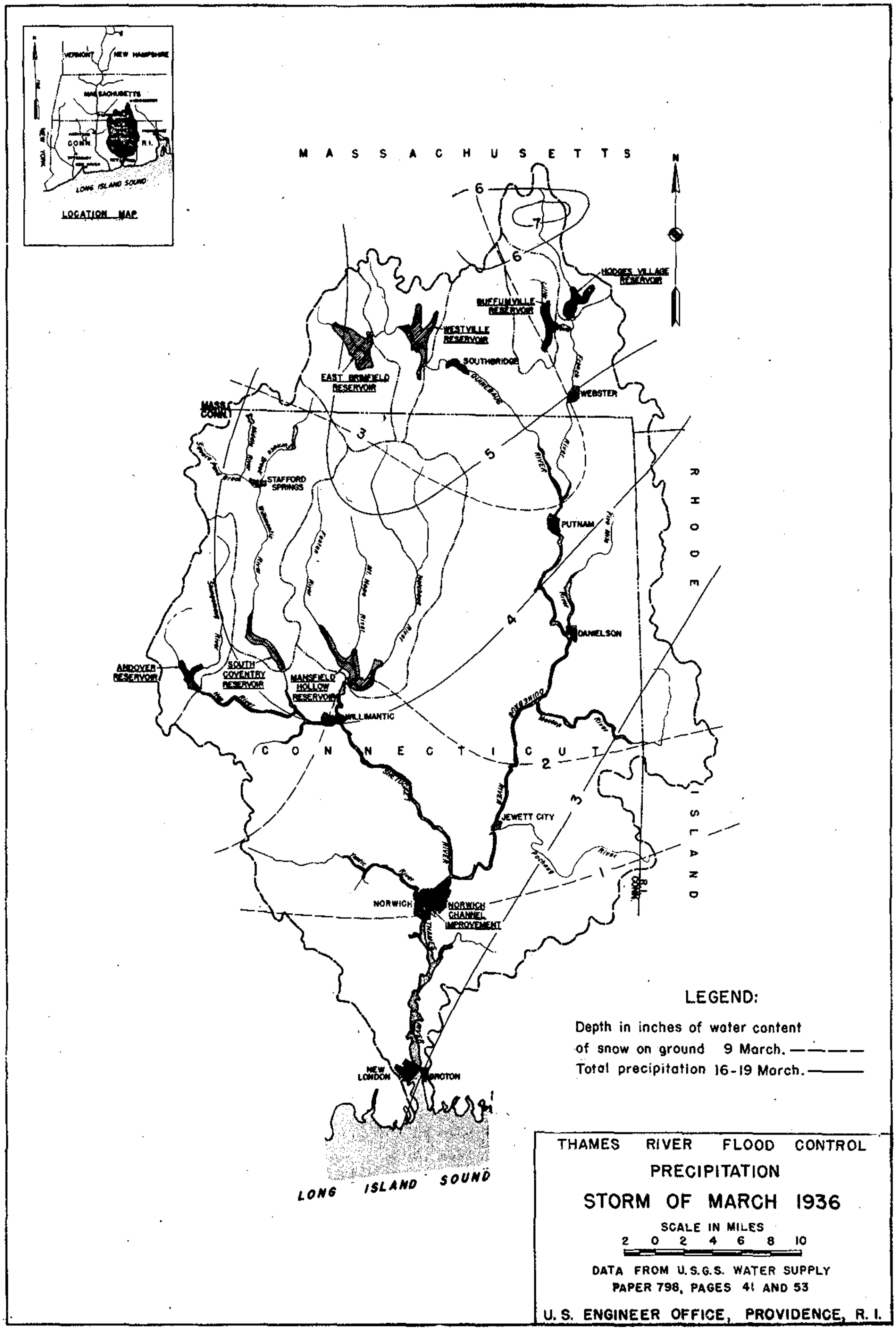
RAINFALL AND STREAM GAGES

IN VICINITY OF

THAMES RIVER WATERSHED

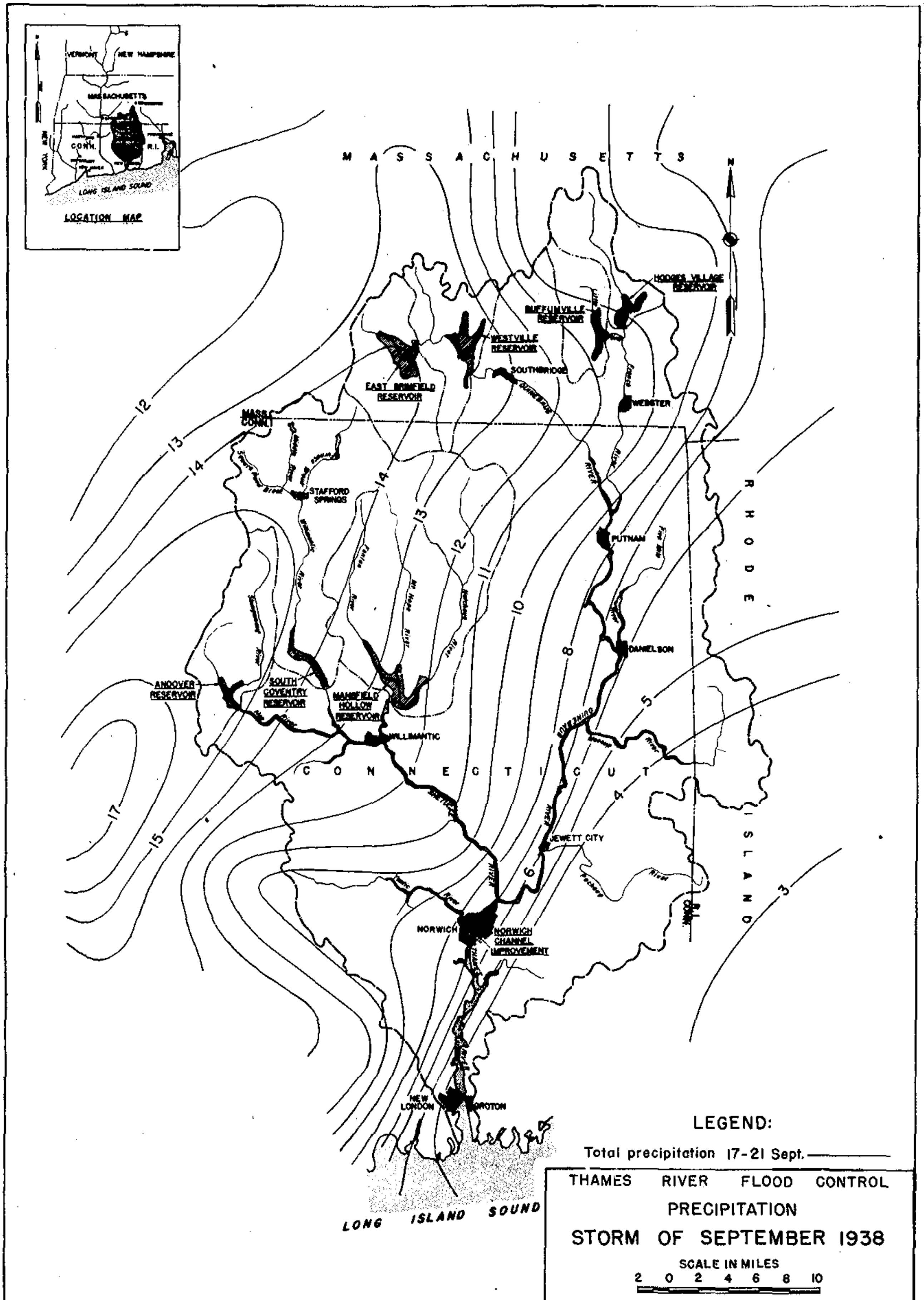
SCALE 5 0 5 10 MILES

U.S. ENGINEER OFFICE, PROVIDENCE, R.I.

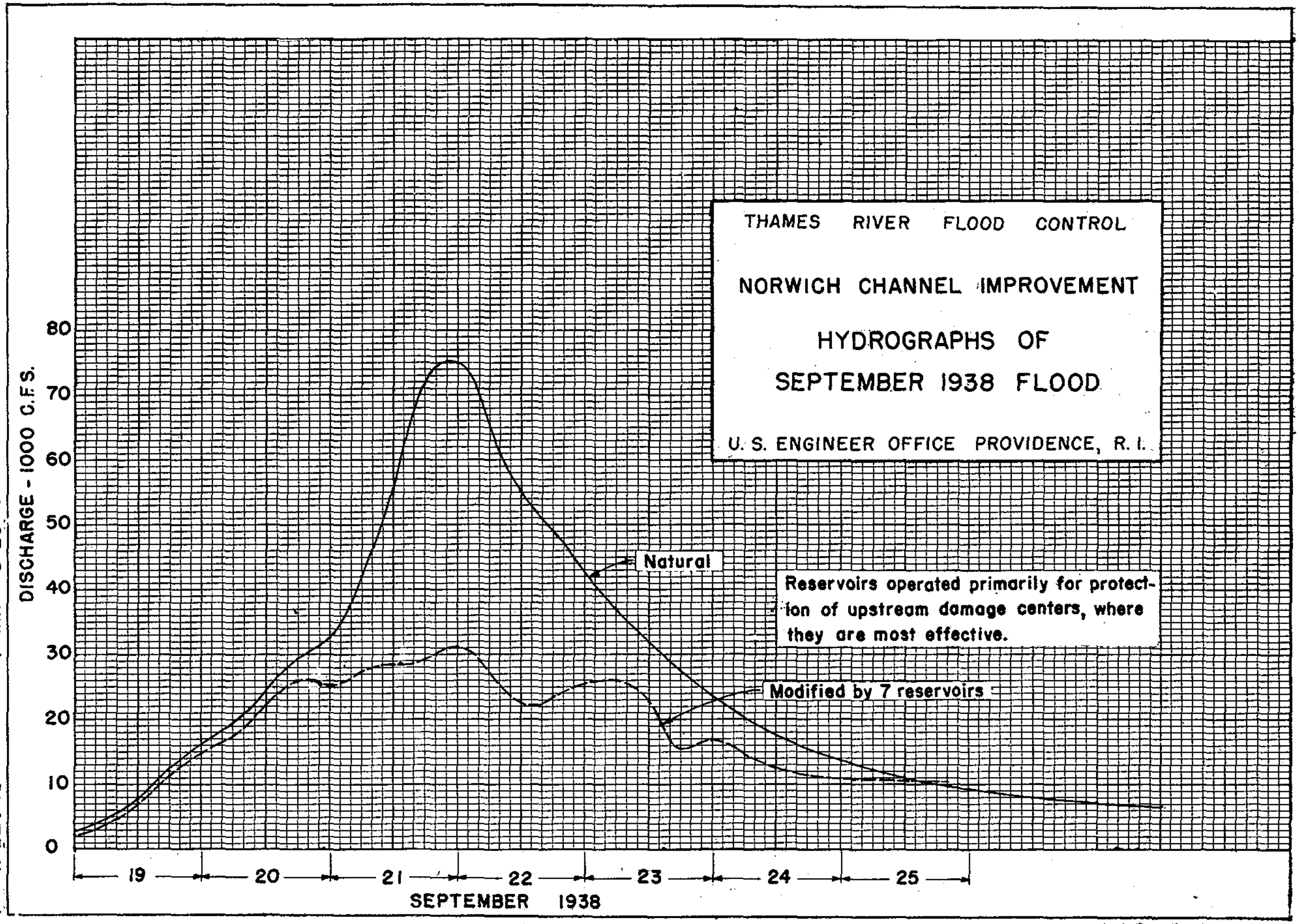



A. OF D. NW-1

PLATE NO. VIII

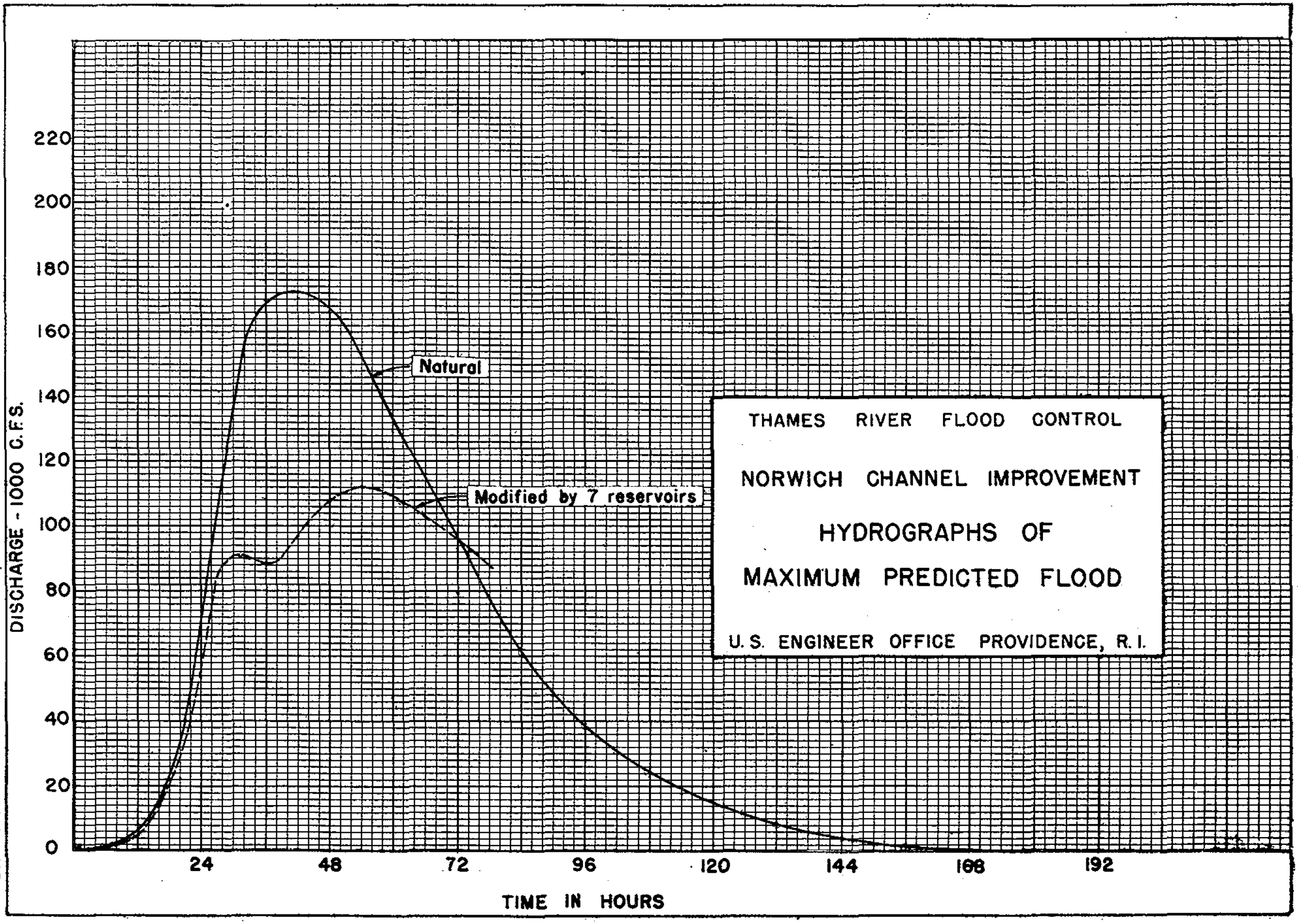



A. OF D. NW-1 PLATE NO. IX




A. OF D. NW-I

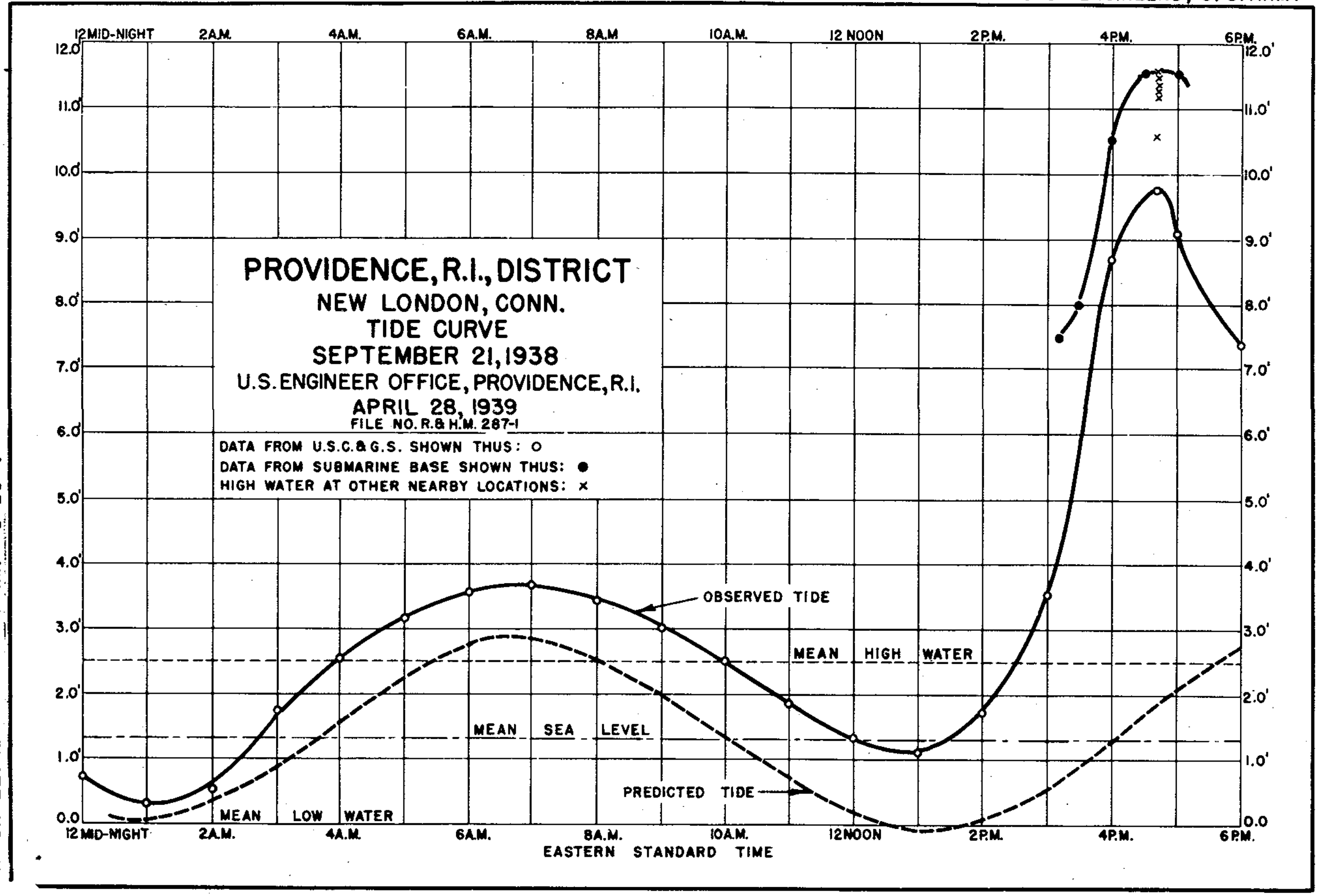
PLATE NO. X




A. OF D. NW-I

PLATE NO. XI

WAR DEPARTMENT CORPS OF ENGINEERS, U. S. ARMY



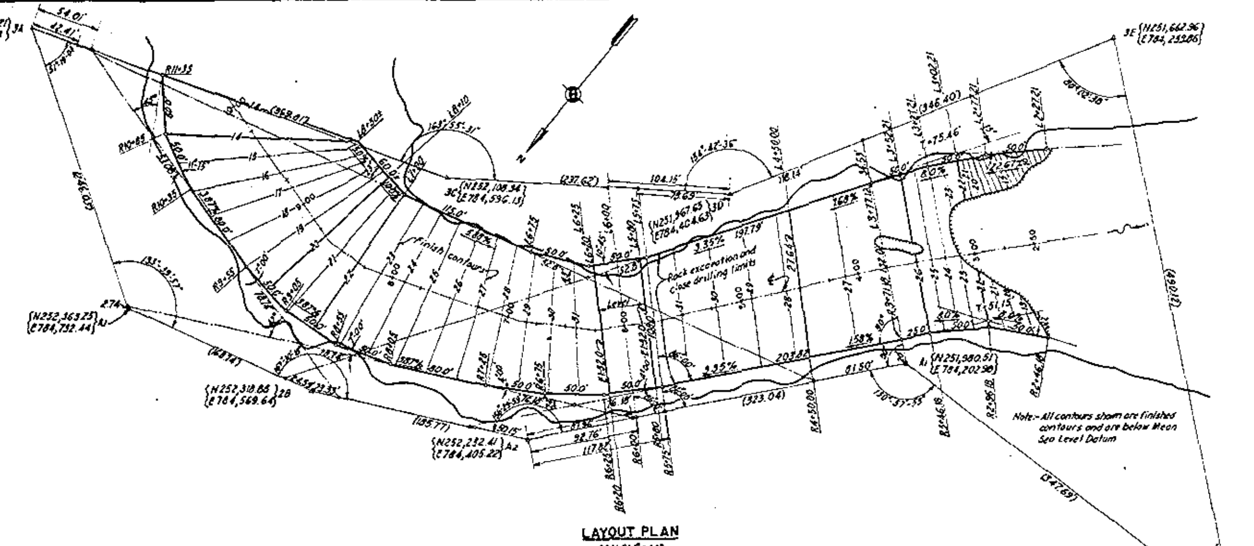

A. OF D. NW-1

PLATE NO XII

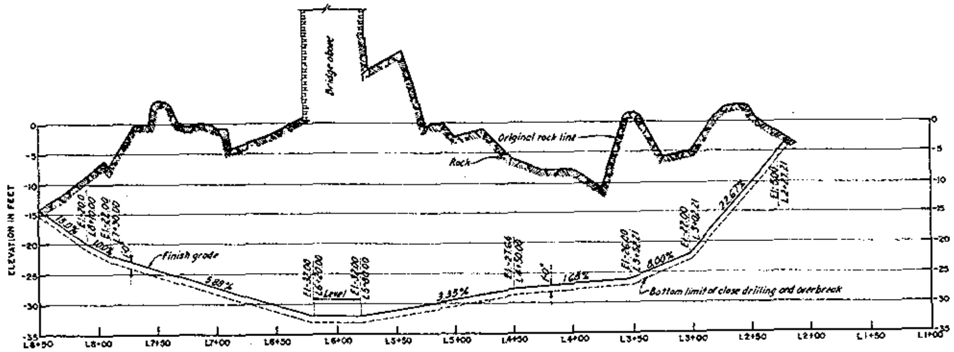
A. OF D. NW-1

WAR DEPARTMENT

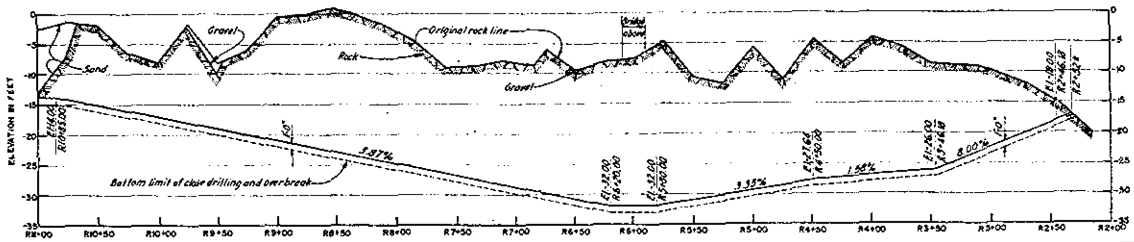
CORPS OF ENGINEERS, U. S. ARMY




LAYOUT PLAN
SCALE: 1" = 40'




PROFILE ALONG LEFT EXCAVATION LIMIT
SCALE: HOR. 1" = 40' VERT. 1" = 8'




PROFILE ALONG RIGHT EXCAVATION LIMIT
SCALE: HOR. 1" = 40' VERT. 1" = 8'

NOTES
Elevations refer to Mean Sea Level Datum.
Coordinates refer to the State of Connecticut Plane Coordinate System.

| KEY | DATE | REVISION (indicated by △) | REV BY | CK BY | AP BY |
|---|---|---|---|---|---|

△ THIS SHEET SUPERSEDES SHEET NO. 3 FILE NO. TH-10-1003

THAMES RIVER FLOOD CONTROL
NORWICH CHANNEL IMPROVEMENT
NORWICH, CONN.
LAYOUT PLAN AND GRADE PROFILES
SHETUCKET RIVER CONNECTICUT
IN 6 SHEETS SCALE: 1 IN. = 40 FT. SHEET NO. 3
U.S. ENGINEER OFFICE, PROVIDENCE, R.I., OCT. 1945
SUBMITTED: SENIOR ENGINEER, HEAD, DESIGN SECTION
APPROVAL RECOMMENDED: SENIOR ENGINEER, ACTING CHIEF ENGINEERING DIV.
APPROVED: COL. CORPS OF ENGINEERS, DISTRICT ENGINEER
PREPARED BY: DESIGN SECTION
DRAWN: H.E.B.
TRACED: E.S.S.
CHECKED
FILE NO. TH-10-1009

PLATE NO. XIII

WAR DEPARTMENT

CORPS OF ENGINEERS, U. S. ARMY

A. OF D. NW-I

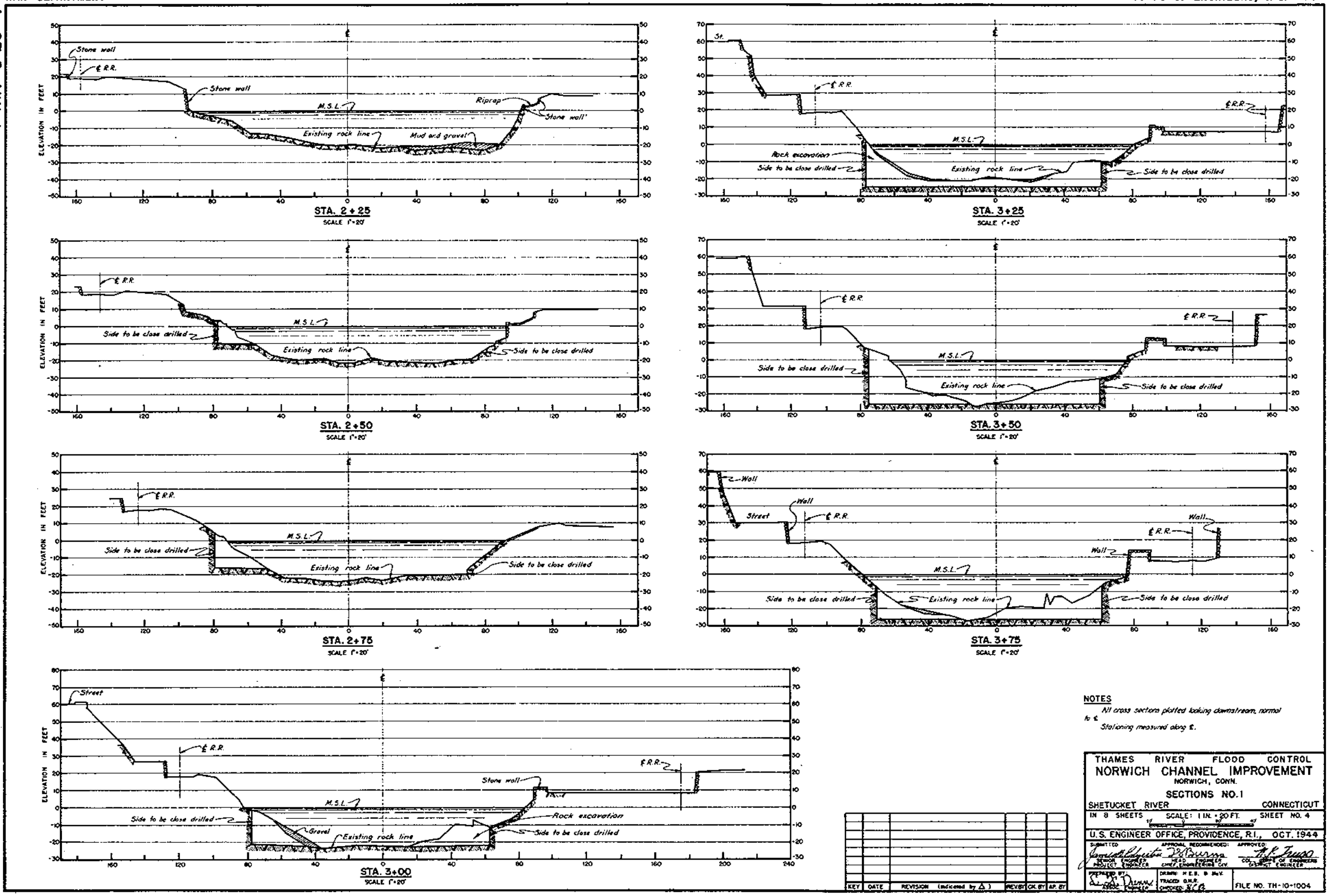



PLATE NO. XIV

A. OF D. NW-I

WAR DEPARTMENT

CORPS OF ENGINEERS, U. S. ARMY

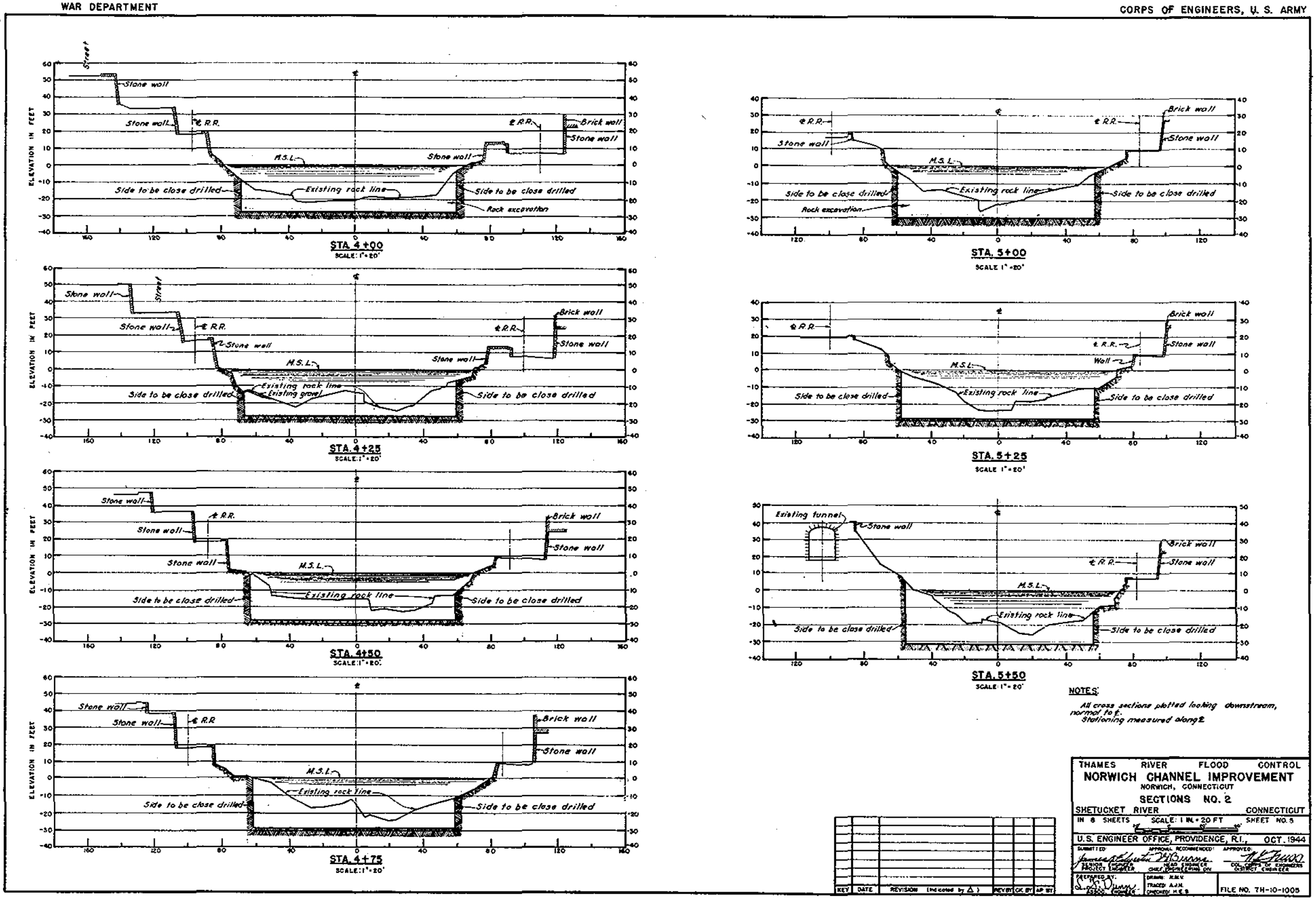
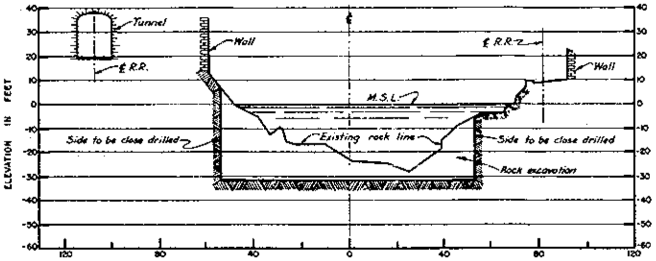



PLATE NO. XV

WAR DEPARTMENT

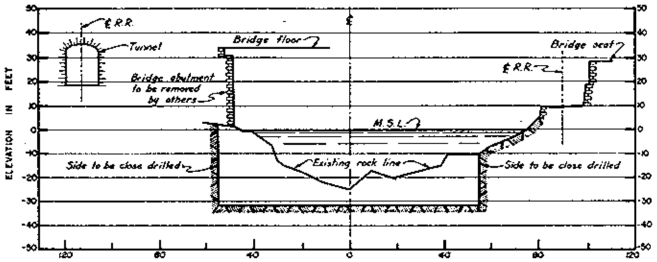
CORPS OF ENGINEERS, U. S. ARMY

A. OF D. NW-I



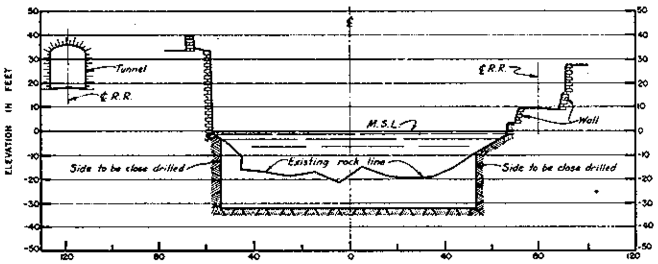

STA. 5+75

SCALE 1"=20'




STA. 6+00

SCALE 1"=20'




STA. 6+25

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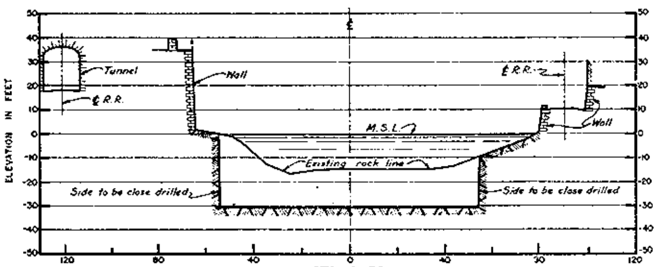


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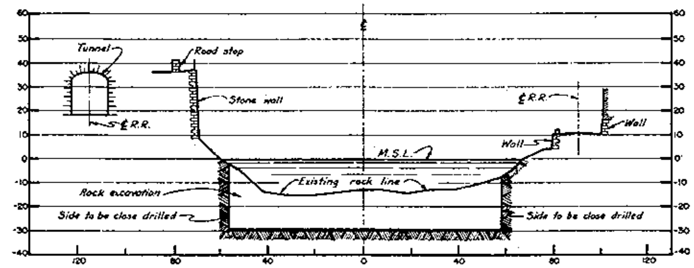


STA. 6+75

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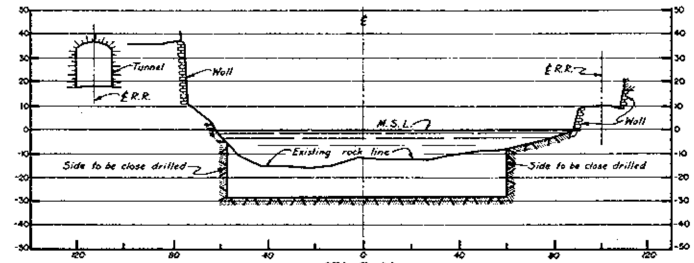
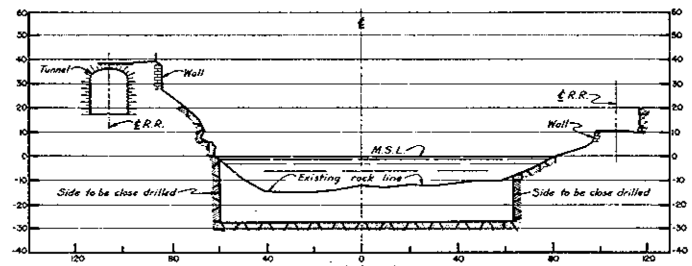



STA. 7+00

SCALE 1"=20'




STA. 7+25

SCALE 1"=20'

NOTES:

All cross sections plotted looking downstream, normal to ℄.

Stationing measured along ℄

| KEY | DATE | REVISION (Indicated by △) | REV BY | CK. BY | AP. BY |
|---|---|---|---|---|---|
| | | | | | |

THAMES RIVER FLOOD CONTROL

NORWICH CHANNEL IMPROVEMENT

NORWICH, CONN.

SECTIONS NO. 3

SHETUCKET RIVER — CONNECTICUT

IN 8 SHEETS — SCALE: 1 IN. = 20 FT. — SHEET NO. 6

U.S. ENGINEER OFFICE, PROVIDENCE, R.I., OCT. 1944

SUBMITTED — SENIOR ENGINEER, PROJECT ENGINEER

APPROVAL RECOMMENDED: HEAD ENGINEER, CHIEF ENGINEERING DIV.

APPROVED: COL., CORPS OF ENGINEERS, DISTRICT ENGINEER

PREPARED BY:

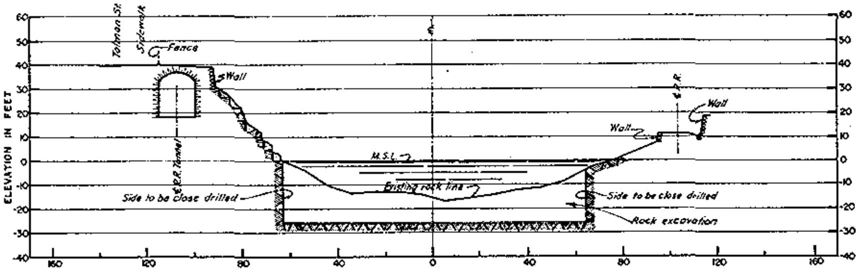
DRAWN R.S.B.

TRACED D.H.R.

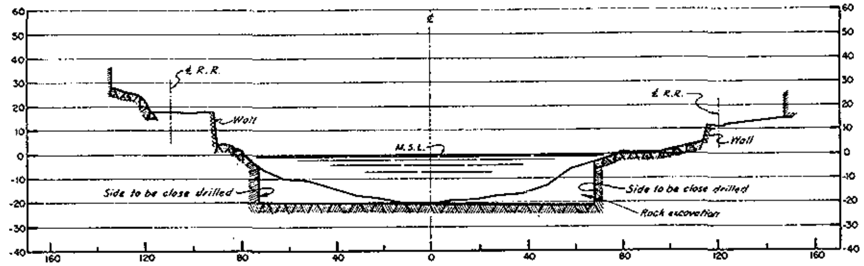
CHECKED R.E.B.

FILE NO. TH-IC-1006

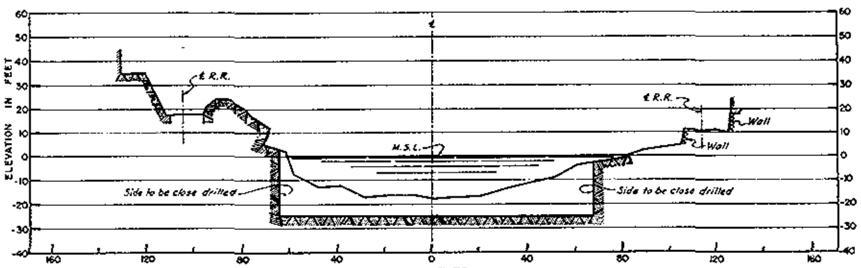
PLATE NO. XVI



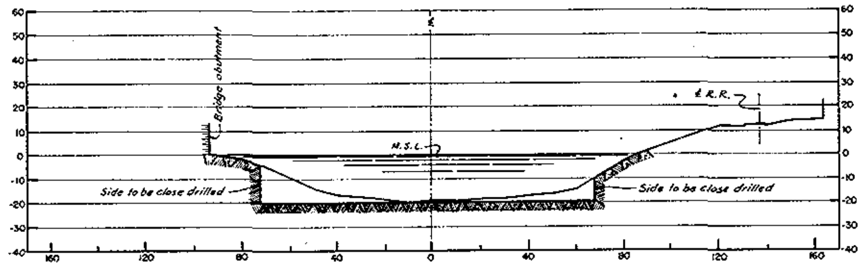

**STA. 7+50**
SCALE 1"=20'



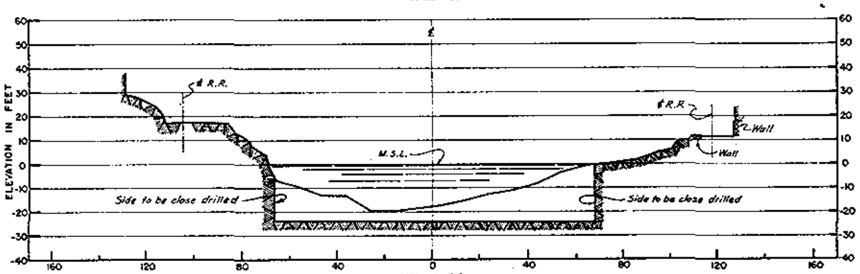

**STA. 8+50**
SCALE 1"=20'



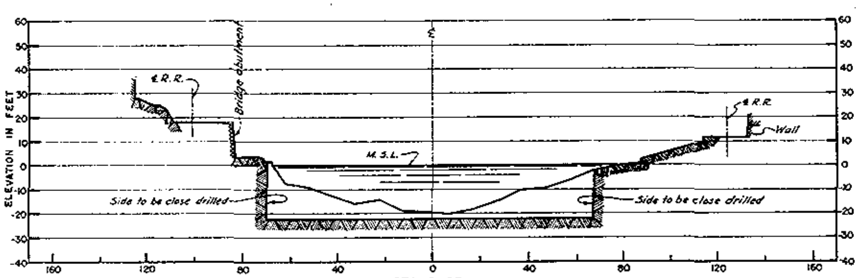

**STA. 7+75**
SCALE 1"=20'




**STA. 8+75**
SCALE 1"=20'




**STA. 8+00**
SCALE 1"=20'




**STA. 8+25**
SCALE 1"=20'

NOTES

All cross sections plotted looking downstream, normal to ℄.
Stationing measured along ℄.

| KEY | DATE | REVISION Indicated by Δ 1 | REV. BY | CK. BY | AP. BY |
|---|---|---|---|---|---|

THAMES RIVER FLOOD CONTROL
NORWICH CHANNEL IMPROVEMENT
NORWICH, CONN.
SECTIONS NO. 4

SHETUCKET RIVER — CONNECTICUT

IN 8 SHEETS — SCALE 1" = 20' — SHEET NO. 7

U. S. ENGINEER OFFICE, PROVIDENCE, R.I., OCT. 1944

SUBMITTED: SENIOR ENGINEER, PROJECT ENGINEER — APPROVAL RECOMMENDED: HEAD ENGINEER, CHIEF, ENGINEERING DIV. — APPROVED: COL. CORPS OF ENGINEERS, DISTRICT ENGINEER

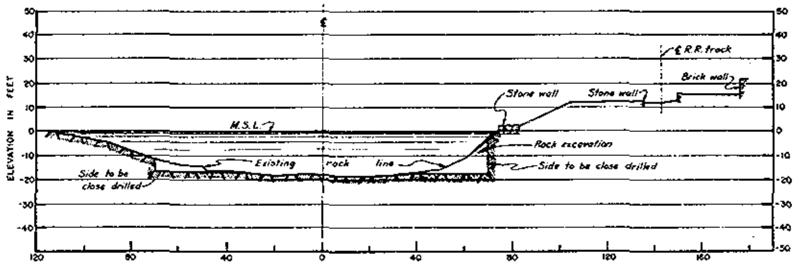
PREPARED BY: ASSOC. ENGINEER — DRAWN: H.E.B. TRACED: H.V.R. CHECKED: H.E.B.

FILE NO. TH-10-1007

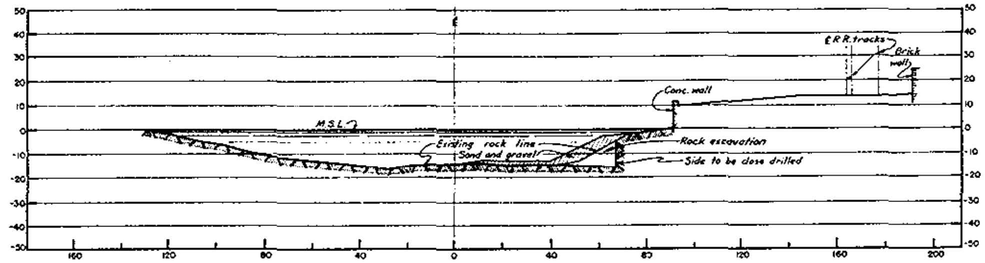
WAR DEPARTMENT

CORPS OF ENGINEERS, U. S. ARMY

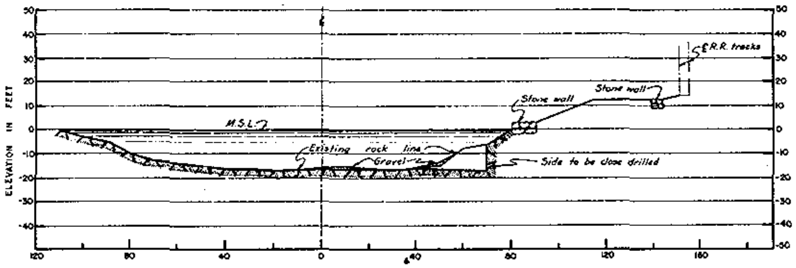
A. OF D. NW-1



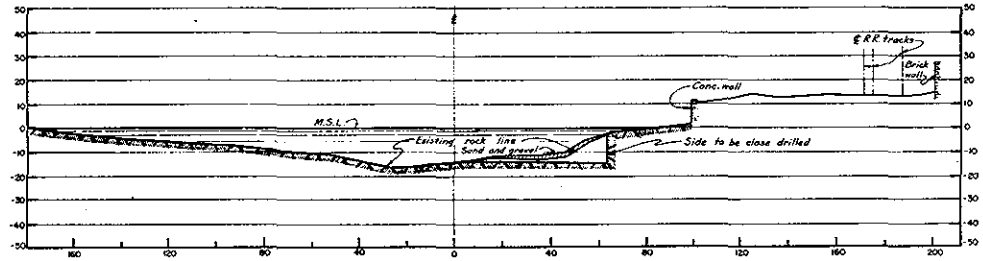

**STA. 9+00**
SCALE 1"=20'



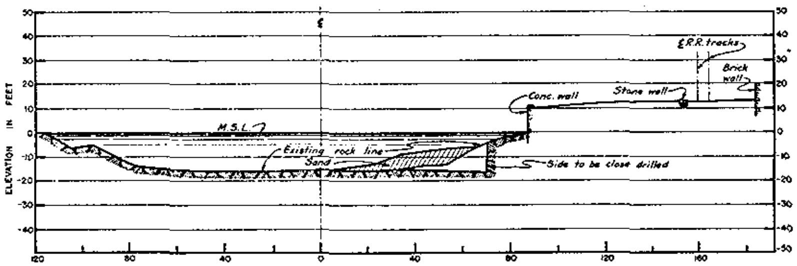

**STA. 9+75**
SCALE 1"=20'




**STA. 9+25**
SCALE 1"=20'




**STA. 10+00**
SCALE 1"=20'




**STA. 9+50**
SCALE 1"=20'

NOTES

All cross sections plotted looking downstream, normal to ℄.
Stationing measured along ℄.

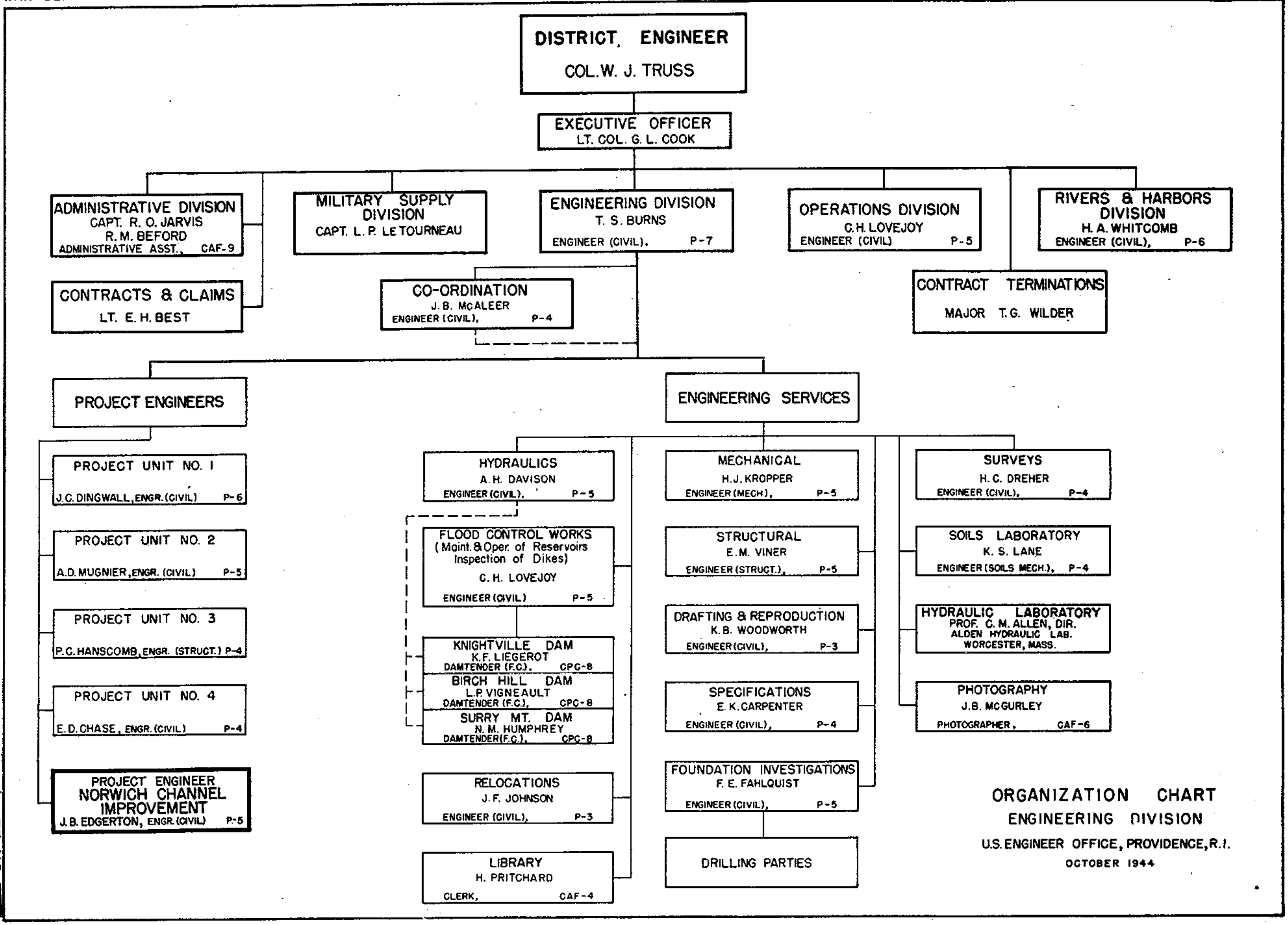
| KEY | DATE | REVISION (indicated by △) | REV BY | CK BY | AP BY |
|---|---|---|---|---|---|

THAMES RIVER FLOOD CONTROL
NORWICH CHANNEL IMPROVEMENT
NORWICH, CONNECTICUT
SECTIONS NO. 5
SHETUCKET RIVER CONNECTICUT
IN 8 SHEETS SCALE: 1 IN. = 20 FT. SHEET NO. 8
U.S. ENGINEER OFFICE, PROVIDENCE, R.I., OCT. 1944
SUBMITTED: SENIOR ENGINEER PROJECT ENGINEER
APPROVAL RECOMMENDED: HEAD ENGINEER CHIEF ENGINEERING DIV.
APPROVED: COL. CORPS OF ENGINEERS DISTRICT ENGINEER
PREPARED BY: ASSOC. ENGINEER
DRAWN: R.E. & H.E.S.
TRACED: D.H.R.
CHECKED:
FILE NO. TH-10-1008

PLATE NO. XVIII

WAR DEPARTMENT

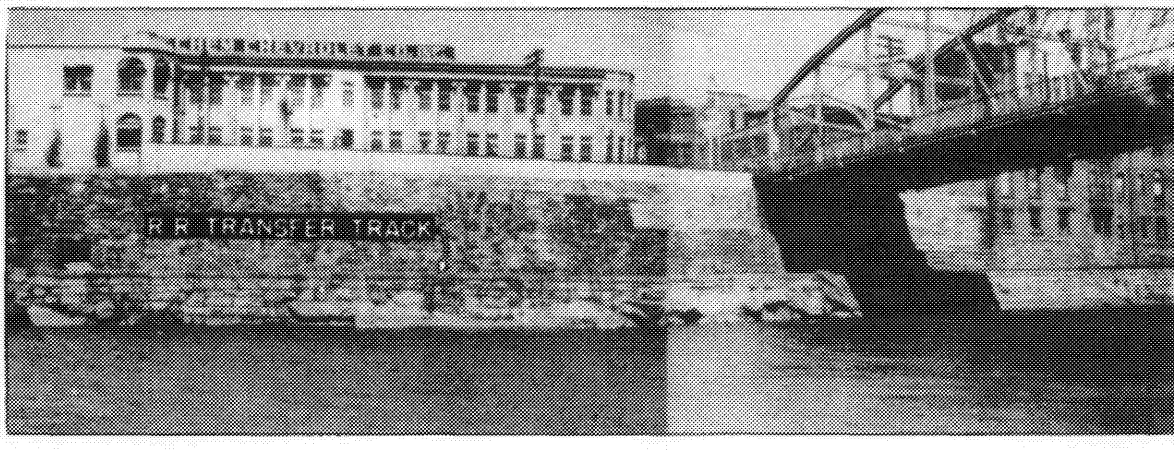
CORPS OF ENGINEERS, U.S. ARMY



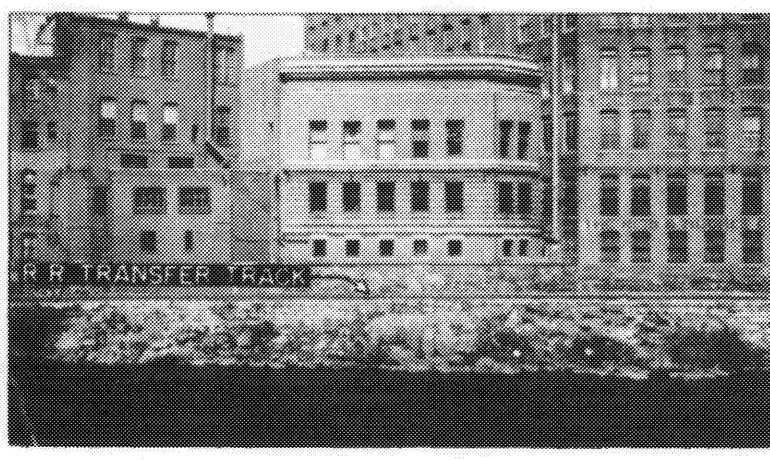

ORGANIZATION CHART
ENGINEERING DIVISION
U.S. ENGINEER OFFICE, PROVIDENCE, R.I.
OCTOBER 1944

A of D NW-I PLATE NO. XIX

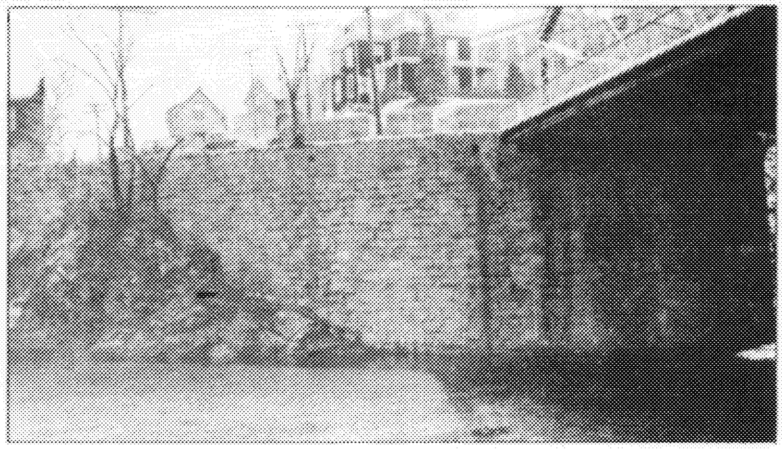

PANORAMIC VIEW OF SOUTH RIVER BANK



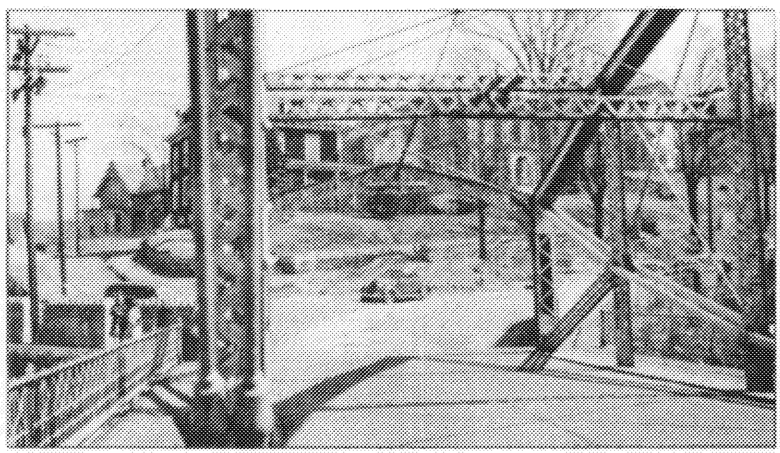

PANORAMIC VIEW OF NORTH RIVER BANK. NOTE RUBBLE MASONRY WALLS AND ROCK OUTCROP NEAR WATER SURFACE.



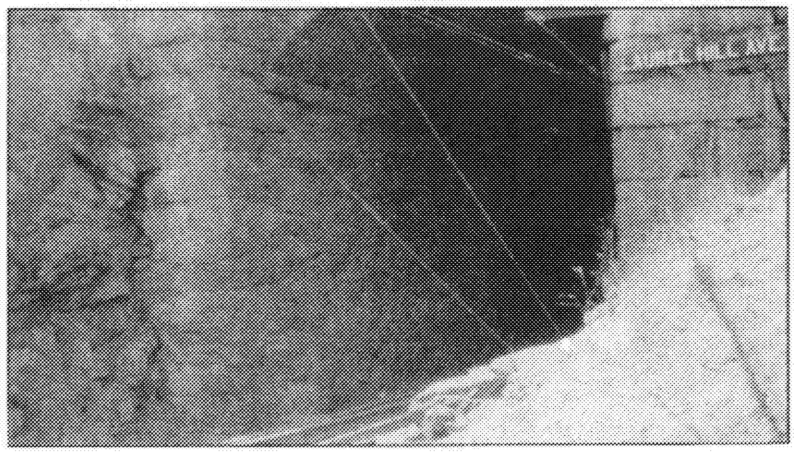

UPSTREAM CONTINUATION OF VIEW OF NORTH RIVER BANK SHOWN ABOVE



VIEW OF SOUTH ABUTMENT LAUREL HILL BRIDGE

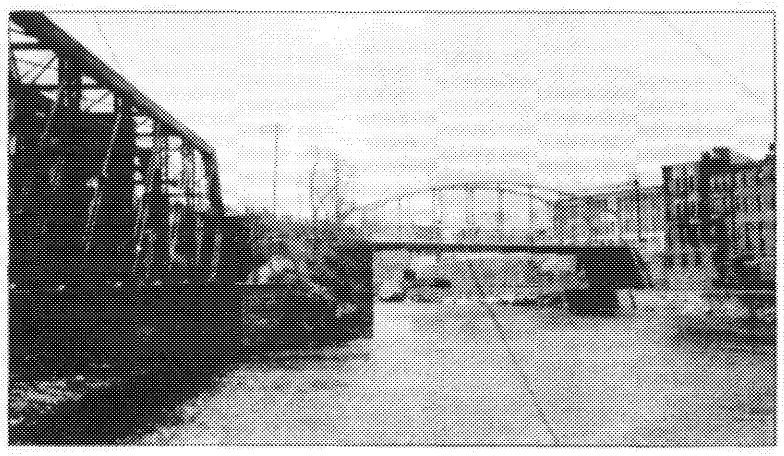


VIEW FROM BRIDGE LOOKING THRU SOUTH PORTAL SHOWING STREET INTERSECTION. BRIDGE TO BE MOVED 25 FEET TOWARDS INTERSECTION

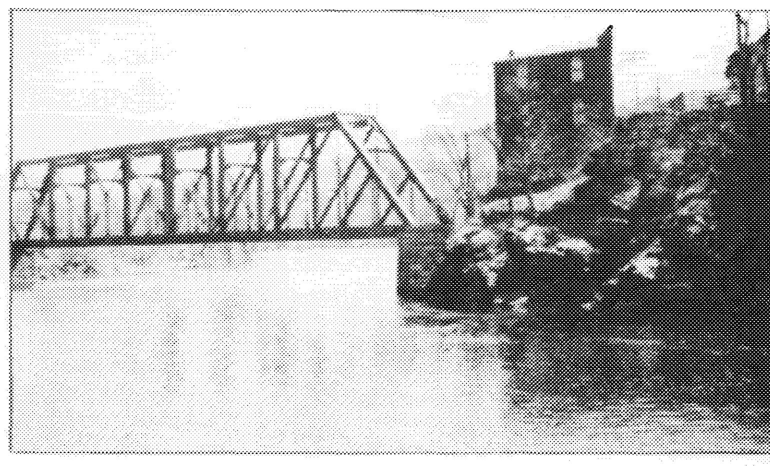


VIEW OF EAST PORTAL OF R. R. TUNNEL
UNDER LAUREL HILL AVENUE

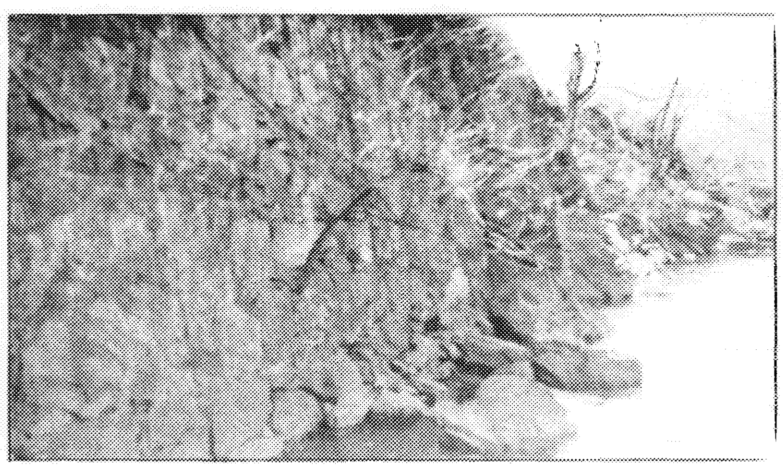
VIEW OF WEST PORTAL OF R R. TUNNEL
UNDER LAUREL HILL AVENUE



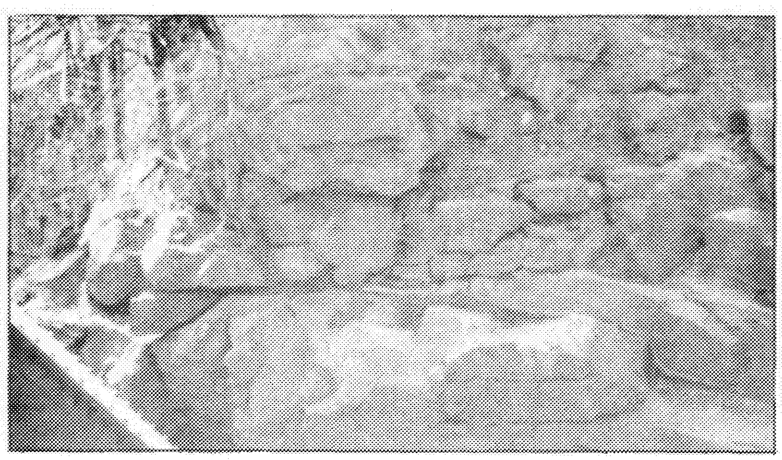
DOWNSTREAM VIEW SHOWING R.R BRIDGE ON LEFT AND LAUREL HILL BRIDGE IN CENTER



VIEW LOOKING UPSTREAM SHOWING RAILROAD BRIDGE AND ITS WEST ABUTMENT ON SOUTH BANK



VIEW OF RUBBLE MASONARY RETAINING WALL SUPPORTING R.R. TRACK ON SOUTH BANK BELOW WEST TUNNEL PORTAL



VIEW OF ROCK FACE JUST SOUTH OF WEST R.R. BRIDGE ABUTMENT. THIS ROCK FORMATION IS TYPICAL OF THE AREA.

NORWICH CHANNEL IMPROVEMENT

ANALYSIS OF DESIGN

ADDENDUM I

TAILWATER ELEVATION AT NORWICH FOR
MAXIMUM FLOOD OF RECORD

JUNE 1945

Given - Observed data - Sept. 1938 Flood (hurricane tide condition):
Shetucket River Q = 75,000 c.f.s.
Water Surface at Norwich: El. 14.7 m.s.l.
Water Surface at New London: El. 8.4 m.s.l.
Length of Reach = 15 miles

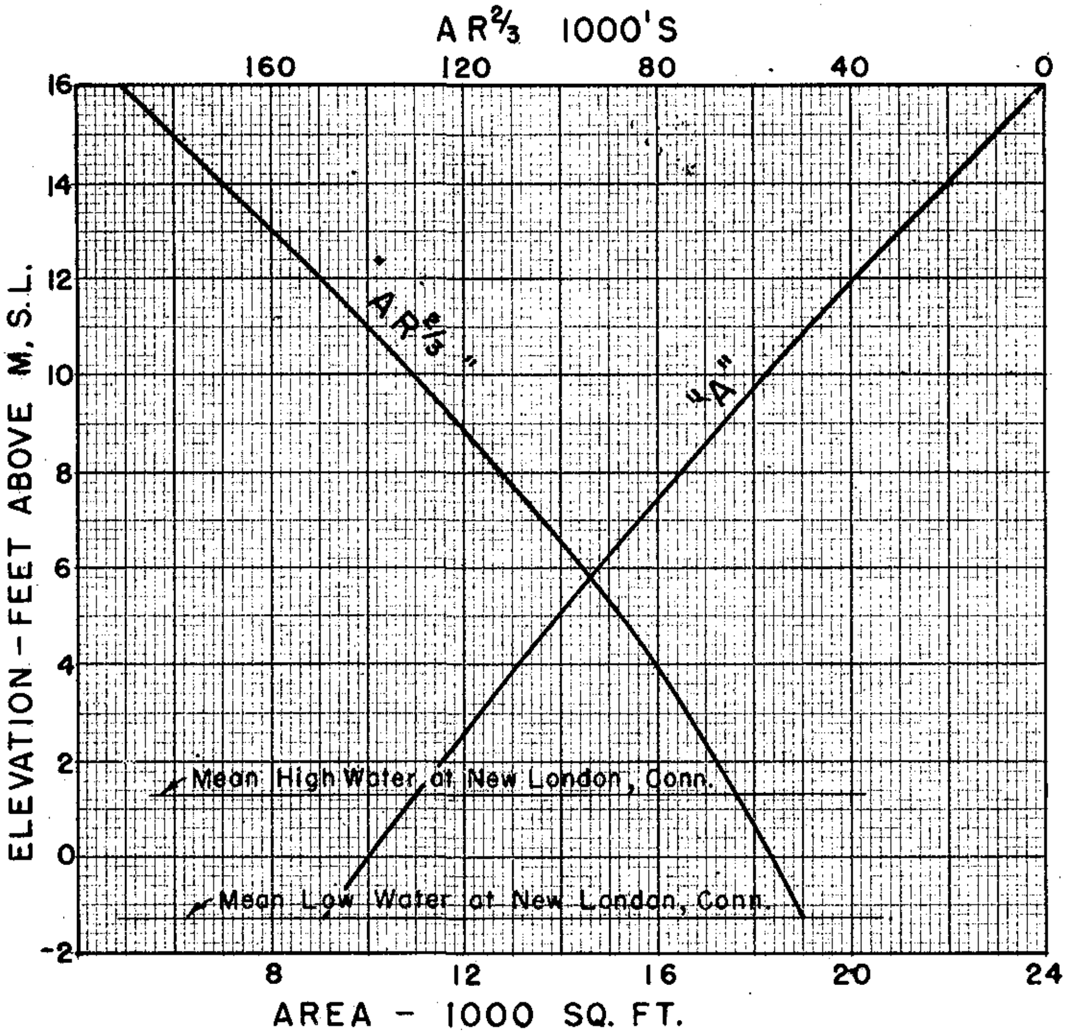
Problem: What is water surface elevation at Norwich when water surface at New London is El. 1.3 m.s.l. (normal tide condition), and Shetucket River Q = 75,000 c.f.s.?

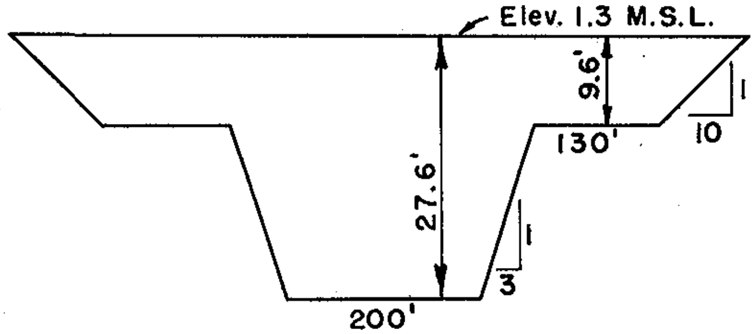
Solution: No bank to bank cross-sections of the Thames River are available. However, the average dimensions of the navigation channel are known. From these data a typical channel section was assumed. This section and curves of A and $AR^{2/3}$ versus elevation are shown on Plate No. A1.

The value of Manning's n for the 1938 flood based on observed water surface elevations at each end of the reach, Shetucket River discharge, and the typical section was determined to be .026. Computation of this value is shown on Plate No. A2.

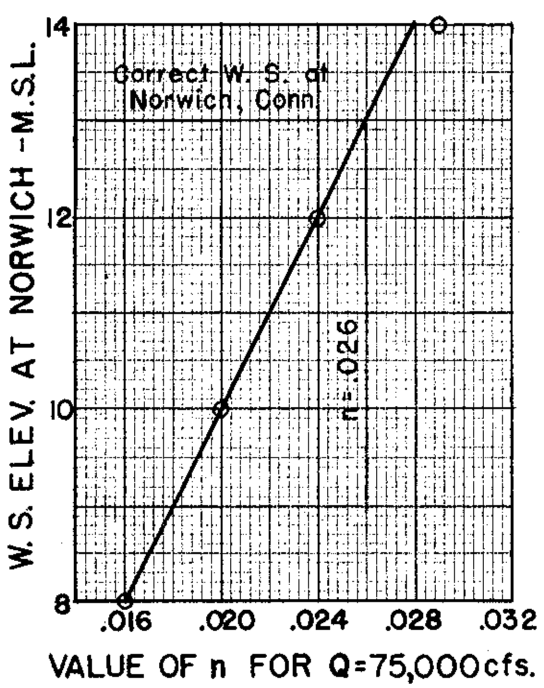
The next step was to determine the values of n for several assumed water surface elevations at Norwich with the water surface at New London at El. 1.3 m.s.l. using the same section and discharge as before. These computations are shown on Plate No. A2.

Values of n were then plotted against the corresponding assumed water surfaces at Norwich as shown on Plate No. A1. The correct water surface elevation at Norwich for Shetucket River Q = 75,000 c.f.s. was taken as elevation 13.0 m.s.l. corresponding to the previously determined value of n = .026.




TYPICAL SECTION




THAMES RIVER FLOOD CONTROL

NORWICH CHANNEL IMPROVEMENT

TAILWATER STUDY

SHETUCKET RIVER CONNECTICUT

U. S. ENGINEER OFFICE PROVIDENCE, R. I.

JUNE 1945

A. OF D. NW-1 PLATE NO. A1

Subject Norwich Channel Improvement
Computation Tailwater Study
Computed by A. H. D. Checked by F. C. T. Date

Sept. 1938 Flood ~ Q = 75,000 c.f.s. ~ Hurricane Tide

| | Norwich | New London |
|---|---|---|
| W. S. Elev. | 14.7 | 8.4 |
| $AR^{2/3}$ | 177,000 | 116,000 |
| A | 22,700 | 16,800 |
| V | 3.31 | 4.46 |
| $h_v$ | 0.17 | 0.31 |
| W.S. + $h_v$ | 14.87 | 8.71 |

$$L = 15 \text{ miles} = 79,200 \text{ ft}$$

$$S = \frac{14.87 - 8.71}{79,200} = .0000778 \qquad S^{1/2} = .00881$$

$$\text{Average } AR^{2/3} = 147,000$$

$$n = \frac{1.486\, AR^{2/3} S^{1/2}}{Q} = \frac{1.486 \times 147,000 \times .00881}{75,000} = \underline{\underline{.026}}$$

M. H. W. at New London ~ Q = 75,000 c.f.s.

| | | |
|---|---|---|
| New London: | W.S. Elev. | 1.3 |
| | $AR^{2/3}$ | 64,000 |
| | A | 11,000 |
| | V | 6.82 |
| | $h_v$ | 0.72 |
| | W.S + $h_v$ | 2.02 |

| Norwich W.S. Elev. | 8.0 | 10.0 | 12.0 | 14.0 |
|---|---|---|---|---|
| Average $AR^{2/3}$ | 88,000 | 97,500 | 107,000 | 117,000 |
| Norwich A | 16,500 | 18,300 | 20,100 | 22,000 |
| " V | 4.55 | 4.10 | 3.73 | 3.41 |
| " $h_v$ | 0.32 | 0.26 | 0.22 | 0.18 |
| " W.S. + $h_v$ | 8.32 | 10.26 | 12.22 | 14.18 |
| $h_f$ for reach | 6.30 | 8.24 | 10.20 | 12.16 |
| S | .0000795 | .000104 | .000129 | .000154 |
| $n = \frac{1.486\, AR^{2/3} S^{1/2}}{Q}$ | .016 | .020 | .024 | .029 |

NORWICH CHANNEL IMPROVEMENT

ANALYSIS OF DESIGN

ADDENDUM II

CHECK ON TAILWATER ELEVATION AT NORWICH
FOR MAXIMUM FLOOD OF RECORD
AS ESTABLISHED BY ADDENDUM I

AND

SHETUCKET RIVER BACKWATER COMPUTATIONS
FOR MAXIMUM FLOOD OF RECORD

SEPTEMBER 1945

## CHECK ON TAILWATER ELEVATION

### Observed Water Surface Elevations

| | |
|---|---|
| Mean high water at New London | El. 1.3 MSL |
| Hurricane tide (21 Sept. 1938): | |
| New London | El. 8.4 MSL |
| Sub Base | El. 10.2 MSL |
| Norwich | El. 14.7 MSL |

### Discharges of 21 Sept. 1938.

| | |
|---|---|
| At mouth of Shetucket River | 75,000 c.f.s. |
| Estimated at mouth of Thames River | 90,000 c.f.s. |

### Computations

Sheet 1: Check on derived values of n for Q = 75,000 c.f.s.

Sheet 2: Norwich tailwater for condition of mean high water at New London based on derived values of n and Q = 75,000 c.f.s.

Sheet 3: Norwich tailwater for condition of mean high water at New London; based on the lower limiting value of water surface elevation at Sub Base.

Computations similar to those on Sheets 1 and 2 but with Q = 90,000 c.f.s. checked the Norwich water surface elevation within 0.04 foot.

### Results

Tailwater elevation computed in Addendum I adopted as correct for design of Norwich Channel Improvement.

Hydraulics Section
U. S. Engineer Office
Providence, R. I.

BACKWATER COMPUTATIONS

Computed by F.C.T.
Date 27 August 1945

Thames River - Flood of 21 September 1938 - Hurricane Tide

| (1) Sect. | (2) Length | (3) Discharge Q | (4) (1000's) Conveyance K | (5) Average Conveyance | (6) n | (7) Slope $s = \left[\frac{Qn}{K}\right]^2$ | (8) Friction Loss (7) x (2) | (9) Area of Section | (10) Mean Velocity (3) / (9) | (11) Velocity Head $h_v$ | (12) $\triangle h_v$ | (13) Head Loss: Contraction | (14) Head Loss: Expansion | (15) Head Loss: Other | (16) Sum of Head Losses | (17) Energy Gradient | (18) Water Surface (17)—(11) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ft. | c.f.s. | 1.486 $AR^{2/3}$ | | | | ft. | sq.ft. | ft./sec. | ft. | ft. | ft. | ft. | ft. | ft. | ft.m.s.l. | ft.m.s.l. |
| N.L. | | 75,000 | 3,250 | | | | | 192,000 | 0.39 | 0.00 | New London Harbor | | | | | 8.40 | 8.4 * |
| | 26,400 | | | 1,935 | .216 | .0000700 | | | | | | | | | 1.85 | | |
| Sub | | | 620 | | | | | 43,600 | 1.72 | .05 | Submarine Base | | | | | 10.25 | 10.2 * |
| | 6,000 | | | 520 | .049 | .0000499 | | | | | | | | | .30 | | |
| Long | | | 420 | | | | | 35,100 | 2.13 | .07 | Long Cove | | | | | 10.55 | 10.48 |
| | 9,000 | | | 385 | | .0000910 | | | | | | | | | .82 | | |
| Gales | | | 350 | | | | | 30,300 | 2.47 | .09 | Gales Ferry | | | | | 11.37 | 11.28 |
| | 3,600 | | | 302 | | .000148 | | | | | | | | | .53 | | |
| Kit | | | 255 | | | | | 20,000 | 3.75 | .22 | Kitemaug | | | | | 11.90 | 11.68 |
| | 5,400 | | | 468 | | .0000614 | | | | | | | | | .33 | | |
| Mas | | | 680 | | | | | 62,800 | 1.19 | .02 | Massapeaug | | | | | 12.23 | 12.21 |
| | 6,000 | | | 522 | | .0000495 | | | | | | | | | .30 | | |
| Stod | | | 365 | | | | | 32,400 | 2.31 | .08 | Stoddard Hill | | | | | 12.53 | 12.45 |
| | 5,900 | | | 322 | | .000130 | | | | | | | | | .77 | | |
| Mo | | | 280 | | | | | 25,900 | 2.90 | .13 | Mohegan | | | | | 13.30 | 13.17 |
| | 9,400 | | | 330 | | .000124 | | | | | | | | | 1.16 | | |
| Th | | | 380 | | | | | 35,400 | 2.12 | .07 | Thamesville | | | | | 14.46 | 14.39 |
| | 6,700 | | | 495 | .049 | .0000551 | | | | | | | | | .37 | | |
| Nor. | | 75,000 | 610 | | | | | 37,900 | 1.98 | .06 | Norwich | | | | | 14.83 | 14.77 |

Checks to .07
(observed W.S. = 14.7)

* Observed high water marks

Hydraulics Section
U. S. Engineer Office
Providence, R. I.

BACKWATER COMPUTATIONS

Computed by F.C.T.
Date 28 August 1945

Thames River Discharge of 21 September 1938 - Normal Tide

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) | (15) | (16) | (17) | (18) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Head Loss | | | | | |
| Sect. | Length | Discharge Q | (1000's) Conveyance K | Average Conveyance | n | Slope $s = \left[\frac{Qn}{K}\right]^2$ | Friction Loss (7) x (2) | Area of Section | Mean Velocity (3) / (9) | Velocity Head $h_v$ | $\triangle h_v$ | Contraction | Expansion | Other | Sum of Head Losses | Energy Gradient | Water Surface (17) — (11) |
| | ft. | c.f.s. | 1.486 $AR^{2/3}$ | | | | ft. | sq.ft. | ft./sec. | ft. | ft. | ft. | ft. | ft. | ft. | ft.m.s.l. | ft.m.s.l. |
| N.L. | | 75,000 | 2,300 | | | | | 156,500 | 0.48 | 0.00 | | | | | | 1.30 | 1.3 * |
| | 26,400 | | | 1,380 | .216 | .000138 | | | | | | | | | 3.64 | | |
| Sub | | | 460 | | | | | 36,100 | 2.08 | .07 | | | | | | 4.94 | 4.87 |
| | 6,000 | | | 372 | .049 | .0000975 | | | | | | | | | .59 | | |
| Long | | | 285 | | | | | 27,500 | 2.72 | .12 | | | | | | 5.53 | 5.41 |
| | 9,000 | | | 270 | | .000185 | | | | | | | | | 1.66 | | |
| Gales | | | 255 | | | | | 24,700 | 3.04 | .14 | | | | | | 7.19 | 7.05 |
| | 3,600 | | | 230 | | .000215 | | | | | | | | | .92 | | |
| Kit | | | 205 | | | | | 17,000 | 4.41 | .30 | | | | | | 8.11 | 7.81 |
| | 5,400 | | | 352 | | .000109 | | | | | | | | | .59 | | |
| Mas | | | 500 | | | | | 52,000 | 1.44 | .03 | | | | | | 8.70 | 8.67 |
| | 6,000 | | | 390 | | .0000888 | | | | | | | | | .53 | | |
| Stod | | | 280 | | | | | 27,400 | 2.74 | .12 | | | | | | 9.23 | 9.11 |
| | 5,900 | | | 252 | | .000213 | | | | | | | | | 1.26 | | |
| Mo | | | 225 | | | | | 22,300 | 3.36 | .18 | | | | | | 10.49 | 10.31 |
| | 9,400 | | | 270 | | .000185 | | | | | | | | | 1.74 | | |
| Th | | | 315 | | | | | 31,500 | 2.38 | .09 | | | | | | 12.23 | 12.14 |
| | 6,700 | | | 440 | .049 | .0000698 | | | | | | | | | .47 | | |
| Nor. | | 75,000 | 565 | | | | | 35,900 | 2.09 | .07 | | | | | | 12.70 | 12.63 |

* Mean High Water

Hydraulics Section
U. S. Engineer Office
Providence, R. I.

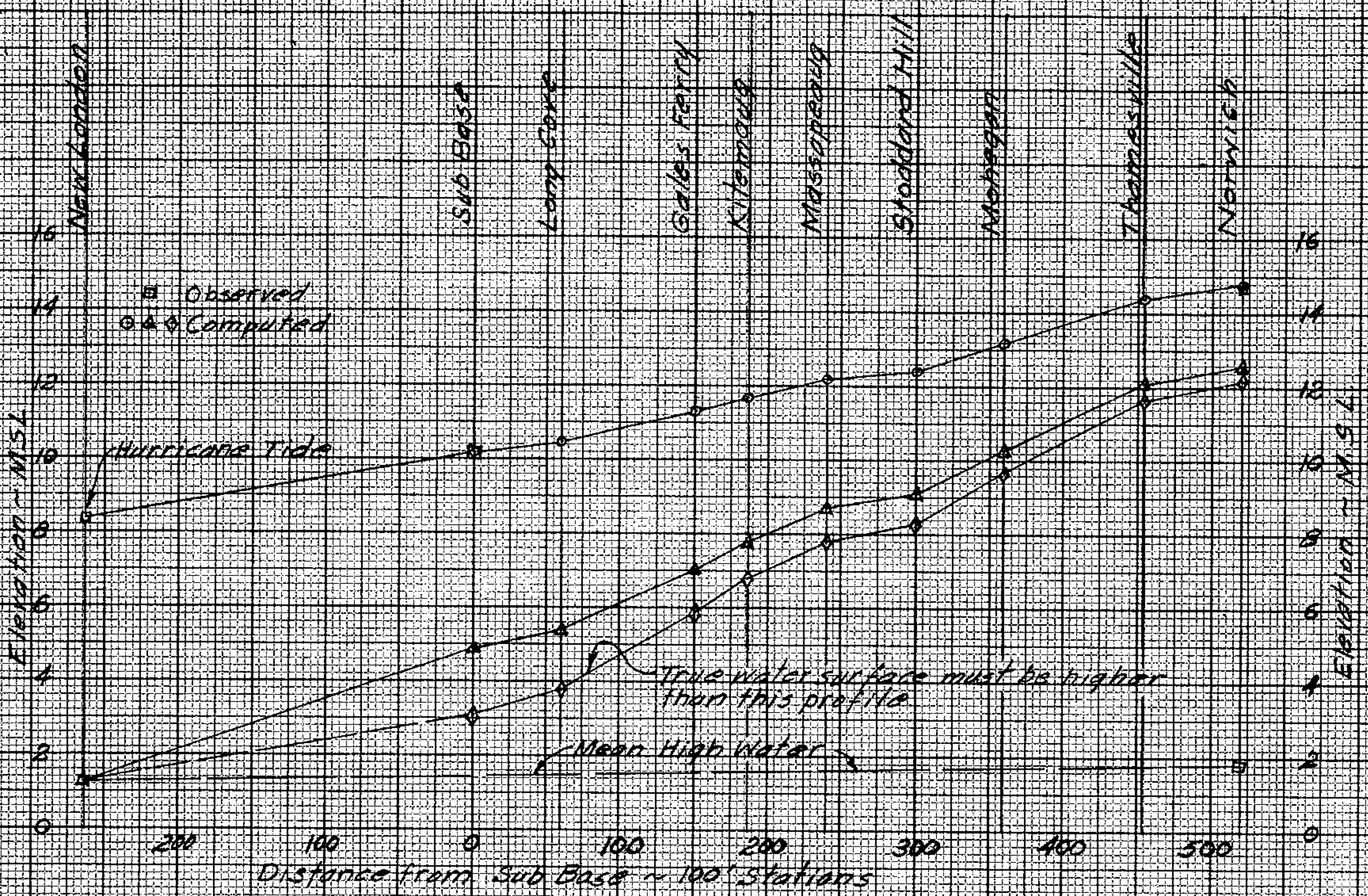
BACKWATER COMPUTATIONS

Computed by F.C.T.
Date 10 September 1945

Thames River - Discharge of 21 September 1938 - Normal Tide

| (1) Sect. | (2) Length | (3) Dis-charge Q | (4) Convey-ance K | (5) Average Convey-ance | (6) n | (7) Slope $s = \left[\frac{Qn}{K}\right]^2$ | (8) Friction Loss (7) x (2) | (9) Area of Section | (10) Mean Velocity (3) / (9) | (11) Velocity Head $h_v$ | (12) $\Delta h_v$ | (13) Head Loss: Contrac-tion | (14) Head Loss: Expan-sion | (15) Head Loss: Other | (16) Sum of Head Losses | (17) Energy Gradient | (18) Water Surface (17) — (11) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ft. | c.f.s. | 1.486 $AR^{2/3}$ | | | | ft. | sq.ft. | ft./sec. | ft. | ft. | ft. | ft. | ft. | ft. | ft.m.s.l. | ft.m.s.l. |
| Sub | | 75,000 | 410 | | | | | 33,600 | 2.23 | .08 | | | | | | 3.18 | 3.1 * |
| | 6,000 | | | 330 | .049 | .000124 | | | | | | | | | .74 | | |
| Long | | | 250 | | | | | 25,200 | 2.98 | .14 | | | | | | 3.92 | 3.78 |
| | 9,000 | | | 240 | | .000235 | | | | | | | | | 2.11 | | |
| Gales | | | 230 | | | | | 23,100 | 3.24 | .16 | | | | | | 6.03 | 5.87 |
| | 3,600 | | | 210 | | .000306 | | | | | | | | | 1.10 | | |
| Kit | | | 190 | | | | | 16,300 | 4.60 | .33 | | | | | | 7.13 | 6.80 |
| | 5,400 | | | 325 | | .000128 | | | | | | | | | .69 | | |
| Mas | | | 460 | | | | | 49,000 | 1.53 | .04 | | | | | | 7.82 | 7.78 |
| | 6,000 | | | 360 | | .000104 | | | | | | | | | .63 | | |
| Stod. | | | 260 | | | | | 26,200 | 2.86 | .13 | | | | | | 8.45 | 8.32 |
| | 5,900 | | | 235 | | .000244 | | | | | | | | | 1.44 | | |
| Mo | | | 210 | | | | | 21,400 | 3.50 | .19 | | | | | | 9.89 | 9.70 |
| | 9,400 | | | 255 | | .000207 | | | | | | | | | 1.87 | | |
| Th | | | 300 | | | | | 30,500 | 2.46 | .09 | | | | | | 11.76 | 11.67 |
| | 6,700 | | | 428 | .049 | .0000737 | | | | | | | | | .52 | | |
| Nor | | 75,000 | 555 | | | | | 35,400 | 2.12 | .07 | | | | | | 12.28 | 12.21 * |

* Note: El. 3.1 at Sub Base established by assuming same loss between Sub Base and New London Harbor as was observed on 21 September 1938. With mean high water in New London Harbor, loss will be greater than that of 21 September 1938 for same Q. Therefor all points on profile must be higher than those computed above.




Thames River
Water Surface Profiles
Discharge of 21 September 1938

# SHETUCKET RIVER BACKWATER

Basic Data

Q = 75,000 c.f.s.

| | |
|---|---|
| 1938 Hurricane tailwater | El. 14.7 MSL |
| Normal tailwater with mean high water at New London | El. 13.0 MSL |
| Observed high water marks as shown on profile | |

Computations

Sheets 1 and 2: Check on derived all-inclusive n values (see profile).

Sheet 3: Water surface profile for condition of normal tailwater.

Sheets 4 and 5: Check computations using derived values of n (friction only) and coefficients for expansion, contraction and bend losses.

Sheet 6: Final check on design proposed in Definite Project Report.

NOTE: - Stationing is that used in Definite Project Report.

Hydraulics Section
U. S. Engineer Office
Providence, R. I.

BACKWATER COMPUTATIONS

Computed by A.H.D.
Date 10 May 1944

Shetucket River - Flood of 21 September 1938 - Hurricane Tide - Existing Channel

| (1) Sect. | (2) Length | (3) Discharge Q | (4) Conveyance K | (5) Average Conveyance | (6) n | (7) Slope $s = \left[\frac{Qn}{K}\right]^2$ | (8) Friction Loss (7) x (2) | (9) Area of Section | (10) Mean Velocity (3) / (9) | (11) Velocity Head $h_v$ | (12) $\Delta h_v$ | (13) Head Loss: Contraction | (14) Head Loss: Expansion | (15) Head Loss: Other | (16) Sum of Head Losses | (17) Energy Gradient | (18) Water Surface (17)—(11) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ft. | c.f.s. | $1.486\ AR^{2/3}$ | | | | ft. | sq.ft. | ft./sec. | ft. | ft. | ft. | ft. | ft. | ft. | ft.m.s.l. | ft.m.s.l. |
| 72+60 | | 75,000 | 167,000 | | | | | 13,900 | 5.40 | .45 | | | | | | 29.75 | 29.3 ** |
| | 450 | | | 145 | .055 | .00081 | | | | | | | | | .36 | | |
| 68+10 | | | 123 | | | | | 12,600 | 5.95 | .55 | | | | | | 29.39 | 28.84 |
| | 410 | | | 128.5 | | .00103 | | | | | | | | | .41 | | |
| 64+00 | | | 134 | | | | | 13,300 | 5.64 | .49 | | | | | | 28.98 | 28.49 |
| | 570 | | | 134.5 | | .00094 | | | | | | | | | .54 | | |
| 58+30 | | | 135 | | | | | 13,200 | 5.68 | .50 | | | | | | 28.44 | 27.94 |
| | 990 | | | 128 | | .00104 | | | | | | | | | 1.03 | | |
| 48+40 | | | 121 | | | | | 9,650 | 7.78 | .94 | | | | | | 27.41 | 26.47 |
| | 700 | | | 148 | | .00078 | | | | | | | | | .55 | | |
| 41+40 | | | 175 | | | | | 13,200 | 5.68 | .50 | | | | | | 26.86 | 26.36 |
| | 750 | | | 172 | | .00058 | | | | | | | | | .43 | | |
| 33+90 | | | 169 | | | | | 15,600 | 4.80 | .36 | | | | | | 26.43 | 26.07 |
| | 540 | | | 145.5 | | .00080 | | | | | | | | | .43 | | |
| 28+50 | | | 122 | | | | | 9,500 | 7.90 | .97 | | | | | | 26.00 | 25.03 |
| Bridge | 40 | | | 120.5 | | .00117 | | | | | | | | | .05 | | |
| 28+10 | | | 119 | | | | | 9,200 | 8.15 | 1.03 | | | | | | 25.95 | 24.92 |
| | 570 | | | 131 | | .00099 | | | | | | | | | .56 | | |
| 22+40 | | | 143 | | | | | 12,200 | 6.15 | .59 | | | | | | 25.39 | 24.80 |
| | 535 | | | 151 | | .00075 | | | | | | | | | .40 | | |
| 17+05 | | | 159 | | | | | 15,250 | 4.91 | .37 | | | | | | 24.99 | 24.62 |
| | * 400 | | | 138.5 | | .00089 | | | | | | | | | .36 | | |
| 12+55 | | | 118 | | | | | 11,900 | 6.05 | .57 | | | | | | 24.63 | 24.06 |
| | 235 | | | 114.5 | | .00130 | | | | | | | | | .31 | | |
| 10+20 | | | 111 | | | | | 9,150 | 8.20 | 1.04 | | | | | | 24.32 | 23.28 |
| Bridge | 30 | | | 105 | .055 | .00154 | | | | | | | | | .05 | | |
| 9+90 | | 75,000 | 99 | | | | | 8,170 | 9.18 | 1.31 | | | | | | 24.27 | 22.96 |

* Shortened length due to flood conditions.

** Interpolated from high water marks.

Hydraulics Section
U. S. Engineer Office
Providence, R. I.

BACKWATER COMPUTATIONS

Computed by A.H.D.
Date 10 May 1944

Shetucket River - Flood of 21 September 1938 - Hurricane Tide - Existing Channel

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) | (15) | (16) | (17) | (18) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Head Loss | | | | | |
| Sect. | Length | Discharge Q | Conveyance K | Average Conveyance | n | Slope $s = \left[\frac{Qn}{K}\right]^2$ | Friction Loss (7) x (2) | Area of Section | Mean Velocity (3) / (9) | Velocity Head $h_v$ | $\triangle h_v$ | Contraction | Expansion | Other | Sum of Head Losses | Energy Gradient | Water Surface (17)—(11) |
| | ft. | c.f.s. | $1.486\ AR^{2/3}$ | | | | ft. | sq.ft. | ft./sec. | ft. | ft. | ft. | ft. | ft. | ft. | ft.m.s.l. | ft.m.s.l. |
| 2+00 | | 75,000 | 82,500 | | | | | 7,950 | 9.43 | 1.38 | | | | | | 16.08 | 14.7 ** |
| | 165 | | | 69.25 | * .100 | .01170 | | | | | | | | | 1.93 | | |
| 3+65 | | | 56 | | | | | 5,200 | 14.4 | 3.22 | | | | | | 18.01 | 14.79 |
| | 210 | | | 48.0 | * .088 | .01890 | | | | | | | | | 3.97 | | |
| 5+75 | | | 40 | | | | | 3,520 | 21.3 | 7.03 | | | | | | 21.98 | 14.95 |
| | 40 | | | 40.5 | .059 | .01190 | | | | | | | | | 0.48 | | |
| 6+15 | | | 41 | | | | | 3,700 | 20.3 | 6.40 | | | | | | 22.46 | 16.06 |
| | 85 | | | 47.25 | | .00878 | | | | | | | | | 0.75 | | |
| 7+00 | | | 53.5 | | | | | 4,270 | 15.9 | 3.92 | | | | | | 23.21 | 19.29 |
| | 105 | | | 57.25 | | .00598 | | | | | | | | | 0.63 | | |
| 8+05 | | | 61 | | | | | 5,300 | 14.1 | 3.08 | | | | | | 23.84 | 20.76 |
| | 75 | | | 73.0 | | .00368 | | | | | | | | | 0.28 | | |
| 8+80 | | | 85 | | | | | 7,500 | 10.0 | 1.55 | | | | | | 24.12 | 22.57 |
| | 110 | | | 92.0 | .059 | .00231 | | | | | | | | | 0.25 | | |
| 9+90 | | 75,000 | 99 | | | | | 8,170 | 9.18 | 1.31 | | | | | | 24.37 | 23.06 |

Checks to .10', see Sheet 1

* Minimum value of $n$.

** Observed high water mark.

Hydraulics Section
U. S. Engineer Office
Providence, R. I.

BACKWATER COMPUTATIONS

Shetucket River - Discharge of 21 September 1938 - Normal Tide - Existing Channel

Computed by A.H.D.
Date 12 March 1945

| (1) Sect. | (2) Length | (3) Discharge Q | (4) Conveyance K | (5) Average Conveyance | (6) * n | (7) Slope $s = \left[\frac{Qn}{K}\right]^2$ | (8) Friction Loss (7) x (2) | (9) Area of Section | (10) Mean Velocity (3) / (9) | (11) Velocity Head $h_v$ | (12) $\triangle h_v$ | (13) Head Loss: Contraction | (14) Head Loss: Expansion | (15) Head Loss: Other | (16) Sum of Head Losses | (17) Energy Gradient | (18) Water Surface (17)—(11) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ft. | c.f.s. | 1.486 $AR^{2/3}$ | | | | ft. | sq.ft. | ft./sec. | ft. | ft. | ft. | ft. | ft. | ft. | ft.m.s.l. | ft.m.s.l. |
| 2+00 | | 75,000 | 72,000 | | | | | 7,300 | 10.3 | 1.65 | | | | | | 14.65 | 13.0 ** |
| | 165 | | | 62.5 | .100 | .0144 | 2.38 | | | | Cols. | 8 & 16 | check to | .20 | 2.18 | | |
| 3+65 | | | 53 | | | | | 4,900 | 15.3 | 3.63 | | | | | | 16.83 | 13.2 |
| | 210 | | | 45 | .088 | .0215 | 4.52 | | | | " | " " | " " | .03 | 4.55 | | |
| 5+75 | | | 37 | | | | | 3,350 | 22.4 | 7.78 | | | | | | 21.48 | 13.7 |
| | 40 | | | 38 | .059 | .0135 | 0.54 | | | | " | " " | " " | .08 | 0.46 | | |
| 6+15 | | | 39 | | | | | 3,600 | 20.8 | 6.72 | | | | | | 21.92 | 15.2 |
| | 85 | | | 44.5 | | .0099 | 0.84 | | | | " | " " | " " | .12 | 0.72 | | |
| 7+00 | | | 50 | | | | | 4,520 | 16.6 | 4.28 | | | | | | 22.68 | 18.4 |
| | 105 | | | 54.25 | | .0067 | 0.70 | | | | " | " " | " " | .11 | 0.81 | | |
| 8+05 | | | 58.5 | | | | | 5,160 | 14.5 | 3.25 | | | | | | 23.55 | 20.3 |
| | 75 | | | 70.75 | | .0039 | 0.29 | | | | " | " " | " " | .10 | 0.39 | | |
| 8+80 | | | 83 | | | | | 7,450 | 10.1 | 1.58 | | | | | | 23.88 | 22.3 |
| | 110 | | | 91 | .059 | .0024 | 0.26 | | | | " | " " | " " | .22 | 0.48 | | |
| 9+90 | | 75,000 | 99 | | | | | 8,170 | 9.18 | 1.31 | | | | | | 24.31 | 23.0 |

**Adopted Values**

| Sta. | E. G. | W. S. |
|---|---|---|
| 2+00 | 14.65 | 13.0 |
| 3+65 | 16.93 | 13.30 |
| 5+75 | 21.46 | 13.68 |
| 6+15 | 21.96 | 15.24 |
| 7+00 | 22.74 | 18.46 |
| 8+05 | 23.49 | 20.24 |
| 8+80 | 23.83 | 22.25 |
| 9+90 | 24.20 | 22.89 |

* Values of n determined for hurricane tide condition. See Sheet 2

** Computed elevation, see Addendum I

Hydraulics Section
U. S. Engineer Office
Providence, R. I.

BACKWATER COMPUTATIONS

Computed by A.H.D.
Date 12 March 1945

Shetucket River - Flood of 21 September 1938 - Hurricane Tide - Existing Channel

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) | (15) | (16) | (17) | (18) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Head Loss | | | | | |
| Sect. | Length | Discharge Q | Conveyance K | Average Conveyance | n | Slope $s = \left[\frac{Qn}{K}\right]^2$ | Friction Loss (7) x (2) | Area of Section | Mean Velocity (3) / (9) | Velocity Head $h_v$ | $\triangle h_v$ | Contraction | Expansion | * Other Bend | Sum of Head Losses | Energy Gradient | Water Surface (17) — (11) |
| | ft. | c.f.s. | $1.486\ AR^{2/3}$ | | | | ft. | sq.ft. | ft./sec. | ft. | ft. | ft. | ft. | ft. | ft. | ft.m.s.l. | ft.m.s.l. |
| 2+00 | | 75,000 | 82,500 | | | | | 7,950 | 9.43 | 1.38 | | (K=.06) | (K=.83) | 84° | | 16.08 | 14.7 |
| | 165 | | | 69.25 | .044 | .00227 | .37 | | | | 1.84 | | 1.53 | | 1.90 | | |
| 3+65 | | | 56 | | | | | 5,200 | 14.4 | 3.22 | | | | | | 17.98 | 14.76 |
| | 210 | | | 48.0 | | .00473 | .99 | | | | 3.81 | | 3.16 | | 4.15 | | |
| 5+75 | | | 40 | | | | | 3,520 | 21.3 | 7.03 | | | | | | 22.13 | 15.10 |
| | 40 | | | 40.5 | | .00662 | .26 | | | | 0.63 | .04 | | | .30 | | |
| 6+15 | | | 41 | | | | | 3,700 | 20.3 | 6.40 | | | | | | 22.43 | 16.03 |
| | 85 | | | 47.25 | | .00488 | .41 | | | | 2.48 | .15 | | .65 | 1.21 | | |
| 7+00 | | | 53.5 | | | | | 4,720 | 15.9 | 3.92 | | | | | | 23.64 | 19.72 |
| | 105 | | | 57.25 | | .00332 | .35 | | | | 0.84 | .05 | | .17 | .57 | | |
| 8+05 | | | 61 | | | | | 5,300 | 14.1 | 3.08 | | | | | | 24.21 | 21.13 |
| | 75 | | | 73.0 | | .00204 | .15 | | | | 1.53 | .09 | | .195 | .43 | | |
| 8+80 | | | 85 | | | | | 7,500 | 10.0 | 1.55 | | | | | | 24.64 | 23.09 |
| | 110 | | | 92.0 | .044 | .00129 | .14 | | | | 0.24 | .01 | | .005 | .16 | | |
| 9+90 | | 75,000 | 99 | | | | | 8,170 | 9.18 | 1.31 | | | | | | 24.80 | 23.49 |
| | | | | | | | 2.67 | | | | | 0.34 | 4.69 | 1.02 | 8.72 | | |

Checks to 0.43, see Sheet 2

* Bend loss assumed = $0.2\ \Sigma\Delta h_v = 0.2 \times 5.09 = 1.02 = 31\%$ Av. $h_v$
Prorate according to partial totals of degrees curvature and $\Sigma\Delta h_v$

Hydraulics Section
U. S. Engineer Office
Providence, R. I.

BACKWATER COMPUTATIONS

Computed by A.H.D.
Date 12 March 1945

Shetucket River - Discharge of 21 September 1938 - Normal Tide - Existing Channel

| (1) Sect. | (2) Length | (3) Discharge Q | (4) Conveyance K | (5) Average Conveyance | (6) n | (7) Slope $s = \left[\frac{Qn}{K}\right]^2$ | (8) Friction Loss (7) x (2) | (9) Area of Section | (10) Mean Velocity (3) / (9) | (11) Velocity Head $h_v$ | (12) $\Delta h_v$ | (13) Head Loss: Contraction | (14) Head Loss: Expansion | (15) Head Loss: Other Bend* | (16) Sum of Head Losses | (17) Energy Gradient | (18) Water Surface (17)—(11) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ft. | c.f.s. | 1.486 $AR^{2/3}$ | | | | ft. | sq.ft. | ft./sec. | ft. | ft. | ft. | ft. | ft. | ft. | ft.m.s.l. | ft.m.s.l. |
| 2+00 | | 75,000 | 72,000 | | | | | 7,300 | 10.3 | 1.65 | | (K=.06) | (K=.83) | 84° | | 14.65 | 13.0 |
| | 165 | | | 62.5 | .044 | .00279 | .46 | | | | 1.98 | | 1.64 | | 2.10 | | |
| 3+65 | | | 53 | | | | | 4,900 | 15.3 | 3.63 | | | | | | 16.75 | 13.12 |
| | 210 | | | 45 | | .00540 | 1.13 | | | | 4.15 | | 3.44 | | 4.57 | | |
| 5+75 | | | 37 | | | | | 3,350 | 22.4 | 7.78 | | | | | | 21.32 | 13.54 |
| | 40 | | | 38 | | .00756 | .30 | | | | 1.06 | .06 | | | .36 | | |
| 6+15 | | | 39 | | | | | 3,600 | 20.8 | 6.72 | | | | | | 21.68 | 14.96 |
| | 85 | | | 44.5 | | .00550 | .47 | | | | 2.44 | .15 | | .65 | 1.27 | | |
| 7+00 | | | 50 | | | | | 4,520 | 16.6 | 4.28 | | | | | | 22.95 | 18.67 |
| | 105 | | | 54.25 | | .00370 | .39 | | | | 1.03 | .06 | | .17 | .62 | | |
| 8+05 | | | 58.5 | | | | | 5,160 | 14.5 | 3.25 | | | | | | 23.57 | 20.32 |
| | 75 | | | 70.75 | | .00217 | .16 | | | | 1.67 | .10 | | .195 | .45 | | |
| 8+80 | | | 83 | | | | | 7,450 | 10.1 | 1.58 | | | | | | 24.02 | 22.44 |
| | 110 | | | 91 | .044 | .00132 | .15 | | | | 0.27 | .02 | | .005 | .18 | | |
| 9+90 | | 75,000 | 99 | | | | | 8,170 | 9.18 | 1.31 | | | | | | 24.20 | 22.89 |
| | | | | | | | 3.06 | | | | | .39 | 5.08 | 1.02 | 9.55 | | |

Checks exactly, see Sheet 3

* Assigned same bend losses as for same Q with hurricane tide. Bend loss = 30% Av. $h_v$

Hydraulics Section
U. S. Engineer Office
Providence, R. I.

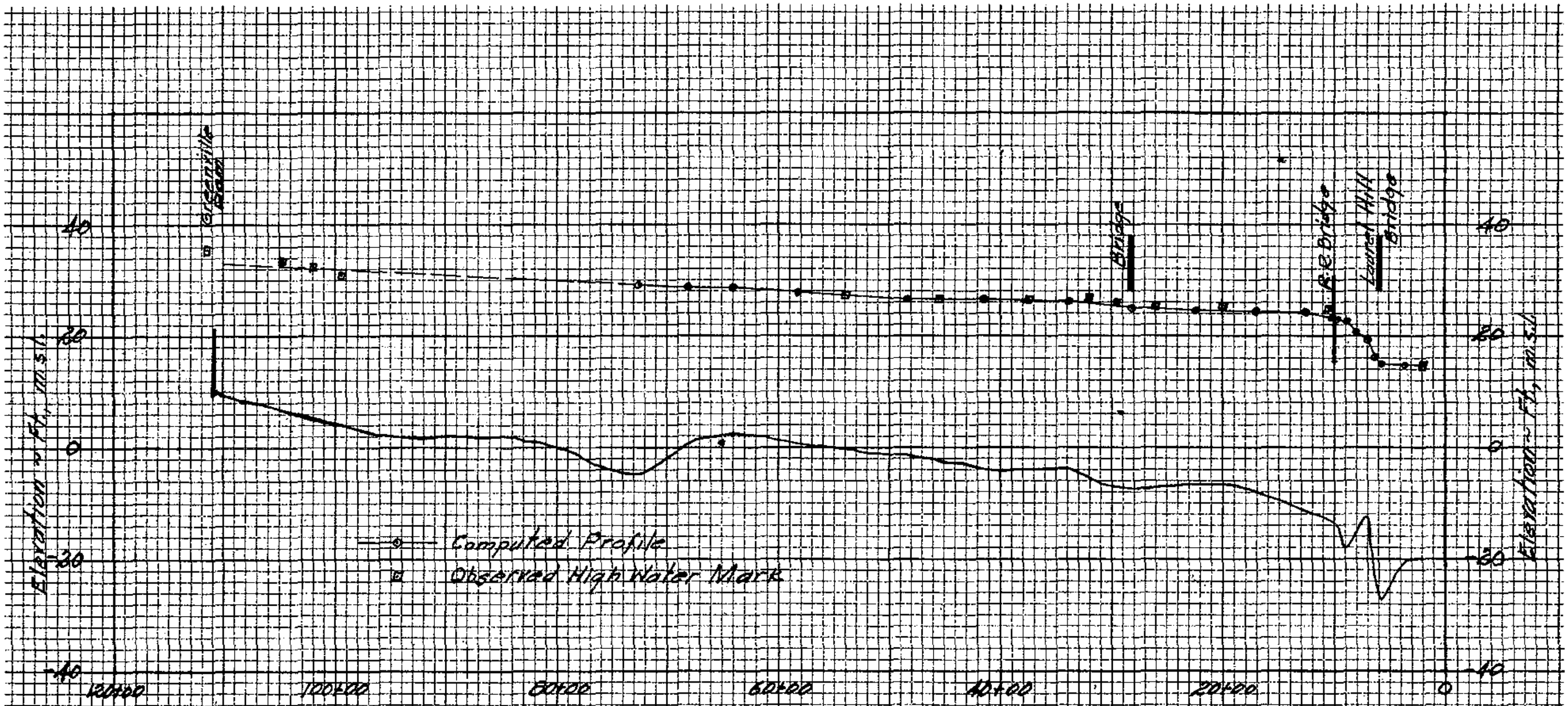
BACKWATER COMPUTATIONS

Computed by A.H.D.
Date 14 March 1945

Shetucket River - Discharge of 21 September 1938 - Normal Tide - Improved Channel

| (1) Sect. | (2) Length | (3) Dis-charge Q | (4) Convey-ance K | (5) Average Convey-ance | (6) n | (7) Slope $s=\left[\frac{Qn}{K}\right]^2$ | (8) Friction Loss (7) x (2) | (9) Area of Section | (10) Mean Velocity (3) / (9) | (11) Velocity Head $h_v$ | (12) $\Delta h_v$ | (13) Head Loss: Contrac-tion | (14) Head Loss: Expan-sion | (15) Head Loss: * Other Bend | (16) Sum of Head Losses | (17) Energy Gradient | (18) Water Surface (17)—(11) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ft. | c.f.s. | 1.486 $AR^{2/3}$ | | | | ft. | sq.ft. | ft./sec. | ft. | ft. | ft. | ft. | ft. | ft. | ft.m.s.l. | ft.m.s.l. |
| 2+00 | | 75,000 | 72,000 | | | | | 7,300 | 10.3 | 1.65 | | (K=.06) | (K=.83) | 84° | | 14.65 | 13.0 |
| | 165 | | | 70.75 | .044 | .00218 | .36 | | | | .78 | - | .65 | | 1.01 | | |
| 3+65 | | | 69.5 | | | | | 6,000 | 12.5 | 2.43 | | | | | | 15.66 | 13.23 |
| | 210 | | | 67 | | .00242 | .51 | | | | .48 | - | .40 | | .91 | | |
| 5+75 | | | 64.5 | | | | | 5,480 | 13.7 | 2.91 | | | | | | 16.57 | 13.66 |
| | 40 | | | 64.75 | | .00260 | .07 | | | | .04 | - | - | | .07 | | |
| 6+15 | | | 65 | | | | | 5,500 | 13.6 | 2.87 | | | | | | 16.64 | 13.77 |
| | 85 | | | 67 | | .00242 | .19 | | | | .17 | .01 | - | .23 | .43 | | |
| 7+00 | | | 69 | | | | | 5,680 | 13.2 | 2.70 | | | | | | 17.07 | 14.37 |
| | 105 | | | 67 | | .00242 | .23 | | | | .09 | - | .07 | .10 | .40 | | |
| 8+05 | | | 65 | | | | | 5,580 | 13.4 | 2.79 | | | | | | 17.47 | 14.68 |
| | 75 | | | 62 | | .00284 | .19 | | | | .17 | .01 | - | .38 | .58 | | |
| 8+80 | | | 59 | | | | | 5,780 | 13.0 | 2.62 | | | | | | 18.05 | 15.43 |
| | 110 | | | 60.5 | .044 | .00297 | .35 | | | | .38 | .02 | - | .08 | .45 | | |
| 9+90 | | 75,000 | 62 | | | | | 6,220 | 12.0 | 2.24 | | | | | | 18.50 | 16.26 |
| | | | | | | | 1.90 | | | | | .04 | 1.12 | *.79 | 3.85 | | |

* Bend loss = 30% Av. $h_v$ = .3 x 2.64 = 0.79.
Distribute on basis of degrees in bend and length of reach.




SHETUCKET RIVER
FLOOD OF 21 SEPTEMBER, 1938